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May 2015

• Welding Creep-Resistant Steels

• Welding in Shipyards

• Bonus: The American Welder

• Stopping Wire Feed Problems

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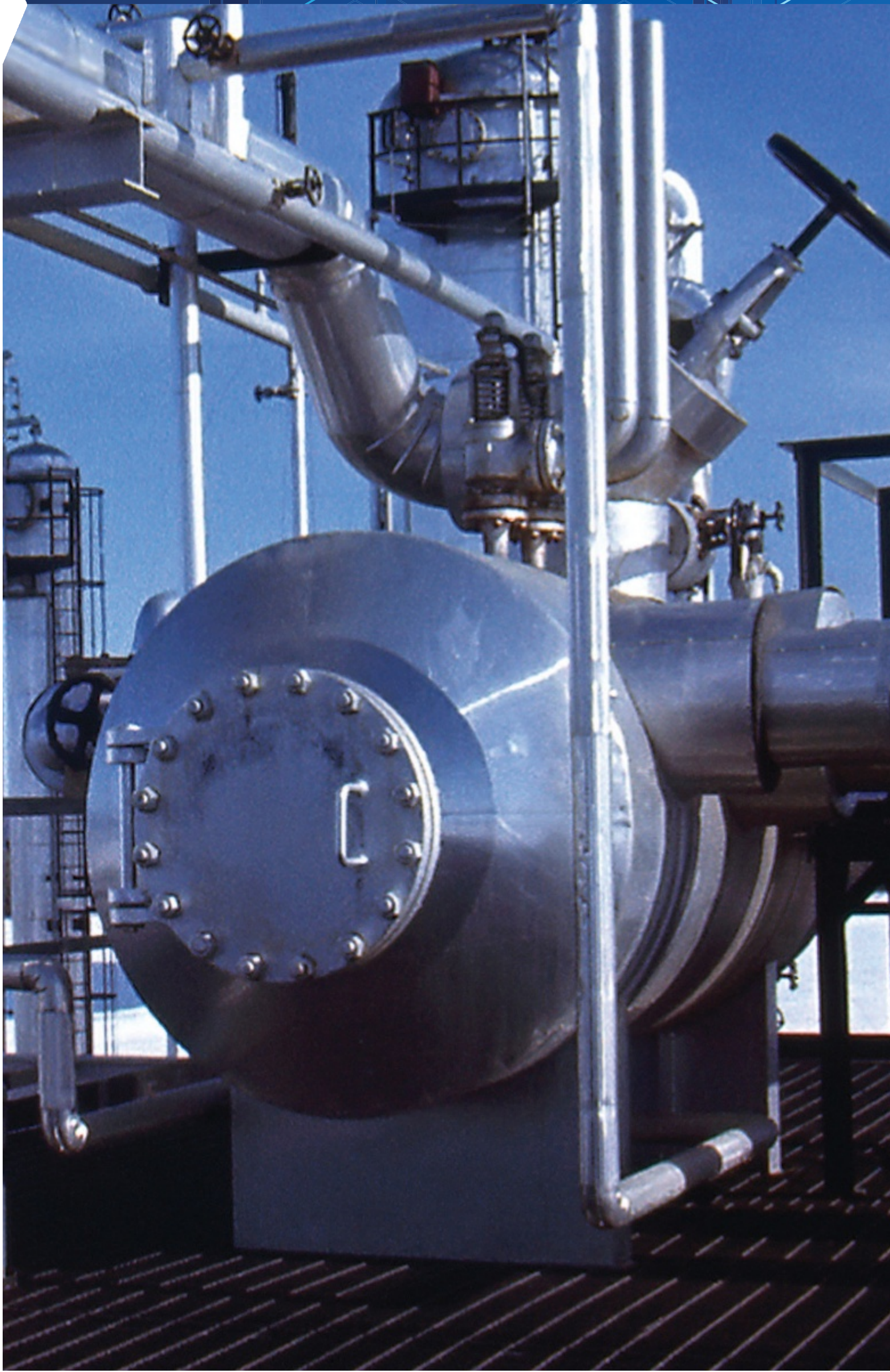

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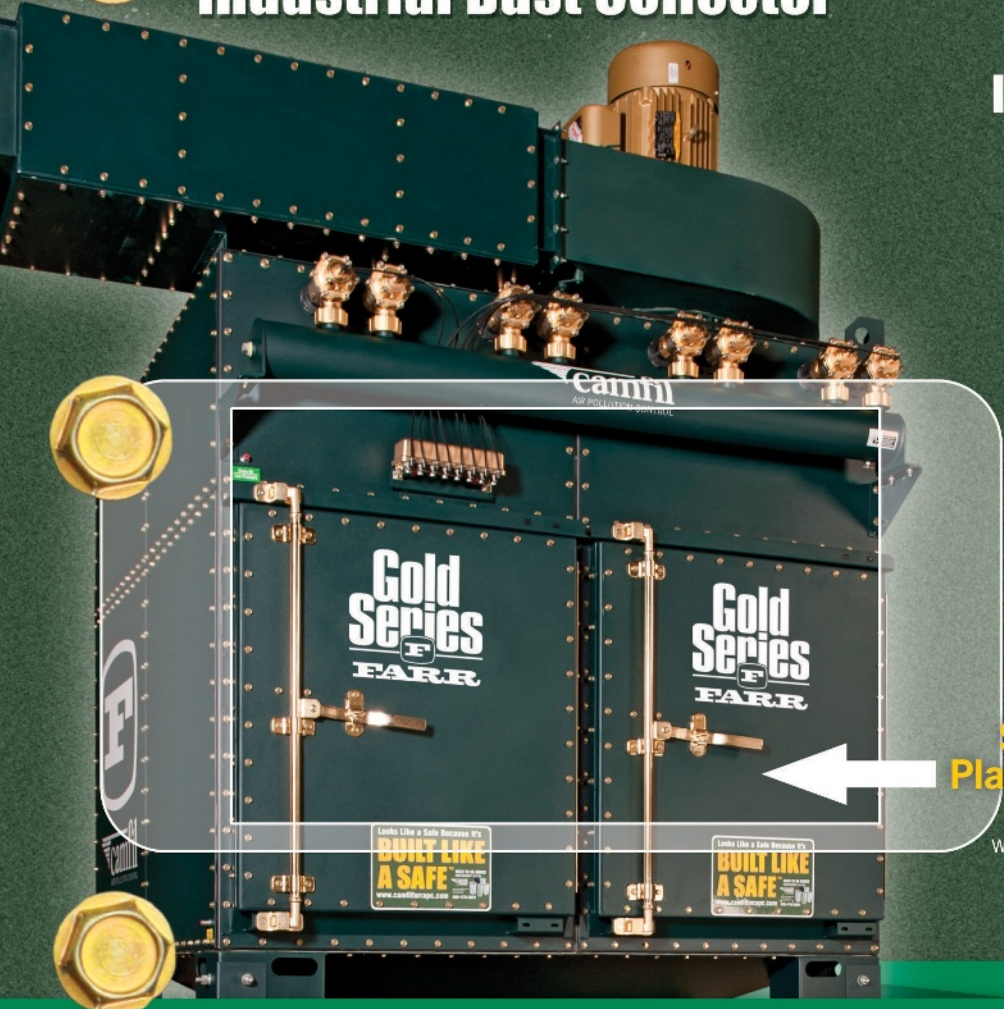

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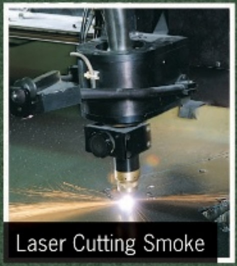

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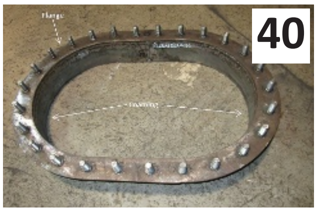

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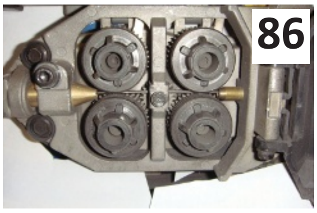

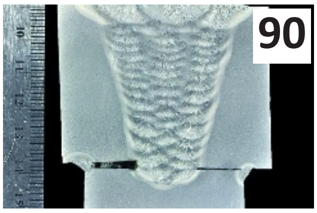

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On the cover: The bow is lifted into place on the U.S. Coast Guard National Security Cutter Hamilton *(WMSL 753), built at Ingalls Shipbuilding in Pascagoula, Miss. (Photo courtesy of Huntington Ingalls Industries.)*

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The Rewards of Being an AWS Volunteer

David L. McQuaid
AWS Vice President

One of the most fulfilling activities I can name in my career is participating as an AWS volunteer. My AWS membership, itself, offers many rewards, such as the monthly *Welding Journal*, Section meetings, the annual FABTECH show, discounts on publications, and much more. But, the greatest satisfaction I get from being an AWS member is what I can give back — in the form of volunteering.

First of all, there is the obvious benefit that being an AWS volunteer allows you to be with others whose work interests parallel your own. Interacting professionally with your peers is both pleasurable and can aid all parties in their daily activities. Perhaps even more important is the personal satisfaction of helping to improve the quality and accuracy of AWS Codes, Standards, and other documents that are widely recognized as being among the best sources available anywhere for obtaining technical welding information. The same participation gives you direct involvement in developing and revising codes and standards that have strong relevance to the industry where you work. Beyond what you can contribute directly, participation in AWS Standards-producing committees lets you be part of a working group even in areas that you would like to understand in greater detail.

On a personal level, volunteer participation allows you to be part of a fraternity of like-minded individuals who are recognized as experts in the welding industry and have experience in the same areas of interest that you have chosen. It also gives you the opportunity to present intriguing questions to others who may have more experience in a specific area. As payback, you may be able to help answer their questions when they come to you.

As a volunteer, you have the the opportunity to contribute to more than 300 AWS documents that give you many choices for enhancing your career, and for improving the competitive edge of the company where you are employed.

On the grass-roots side of volunteerism, there are nearly unlimited opportunities on how far you can go with helping other members and students to get involved with AWS throughout the welding industry. In your local AWS Section, you have the chance to work with students, welders, inspectors, and educators. It is at the local level where you can have the most influence and probably be remembered as a caring and giving person way longer than you would be otherwise. A good explanation of this mentoring aspect of volunteering is given by AWS Vice President John Bray in his editorial in the February 2015 *Welding Journal*. In other words, at the local Section level, it is easy to associate with other AWS members who are involved with welding, manufacturing, teaching, and selling welding equipment and have the same interests that you have.

Volunteer work that reaches the AWS Board of Directors or Officers level may have the furthest-reaching effects of all. As an AWS Director or Officer, you can have direct impact in making policies, determining strategic priorities, and even setting future directions for the Society.

How do you become an AWS volunteer? The simplest way is to contact the Program Manager of any AWS committee that interests you. These individuals are listed in the "Guide to Services" page that appears in the "Society News" Section of each issue of the *Welding Journal*. Another way is to join WEMCO if you are a manufacturer of welding equipment or consumables (e-mail Keila DeMoraes at *kdemoraes@aws.org*). If you are interested in advising on AWS publications, expositions, or marketing, and you have a background to match, we invite you to contact PEMCO Secretary Lorena Cora (e-mail *lcora@aws.org*).

So, with all that said, I urge you to become a volunteer for the Society. You will be doing a favor for yourself, and an even bigger one for the industry that employs you. WJ

"On a personal level, volunteer participation allows you to be part of a fraternity of like-minded individuals who are recognized as experts in the welding industry and have experience in the same areas of interest that you have chosen."

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iiW - International Institute of Welding's Doc. IIW-2509, recommended for publication by Commission VIII "Health, Safety and Environment" states in part: "The experts recommend that use of thoriated electrodes ceases as soon as is practicable and that, until that change is completed, special care is taken to inform workers of the hazards and to implement all the other protective measures which are detailed in the report." http://link.springer.com/article/10.1007/s40194-014-0197-9

AWS - The American Welding Society's Safety and Health FACT Sheet No. 27 states in part: "Choose thorium-free tungsten electrodes such as those containing cerium, lanthanum, yttrium, or zirconium whenever possible." http://www.aws.org/technical/facts/fact-27-201405.pdf

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ESAB Announces Restructuring Plan; Will End Manufacturing in Florence, S.C.

ESAB Welding & Cutting Products is restructuring its North American operations. The plan will integrate ESAB and Victor regional operations and facilities, and will be deployed in phases throughout this year and into 2016.

"This consolidation will enable us to significantly improve the customer experience while leveraging our resources through the application of best practices," said Clay Kiefaber, ESAB president and CEO. "While we regret the loss of associate positions, consolidating our operations will help improve our overall customer responsiveness, and deliver even better performance and future growth."

The following actions are planned:

ESAB's Florence, S.C., manufacturing operations will be consolidated into the company's Denton, Tex., and Hermosillo, Mexico, facilities.

The Denton, Tex., facility will undergo a significant renovation and expansion that will support future growth and accommodate many of the company's North American functions. Upon completion, ESAB will consolidate the distribution operations from the Florence facility and its Roanoke, Tex., distribution facility into the Denton site.

The company's Florence, S.C., finance, accounting, customer service, inside sales, and training functions will also be consolidated into Denton, Tex.

Plasma cutting design engineering and R&D functions will be transitioned to its West Lebanon, N.H., facility.

ESAB will maintain a limited commercial presence in Florence, S.C. (sales, marketing, marketing communications, and capital goods sales) as well as personnel from order engineering , information technology, and human resources. These functions will be relocated to a new facility in Florence in early 2016.

The Florence facility is scheduled to be closed by March 31, 2016. While transfer opportunities will be made available to as many employees as possible, the company estimates 300 associates will be impacted. All associates at ESAB's Roanoke, Tex., facility will transfer to the Denton facility. The Roanoke facility will close by February 29, 2016. No other ESAB locations will be affected.

Yaskawa Celebrates 100-Year Anniversary

Yaskawa has achieved 100 years in business. Pictured above is a custom jigless system with two Motoman handling robots and six welding robots.

Yaskawa Electric Corp., headquartered in Kitakyushu, Japan, commemorates its 100th anniversary this year across all global locations in 28 countries. In addition, the company has renewed its corporate logo and identity.

Yaskawa started in 1915 as a producer of coal mining equipment by founder Daigoro Yasukawa. During the 20th century, various technology advances were developed, including the super synchronous and minertia motors and Motoman® L10 robot.

Presently, the company develops and manufactures robotics and automation systems. It has approximately $3 billion in annual revenue and more than 14,000 global employees.

"Our ability to develop products that help society progress will ensure a prosperous future for Yaskawa and our customers," said Junji Tsuda, the company's representative director, chairman, and president.

Yaskawa America, Inc., a subsidiary overseeing operations in North and South America, is comprised of Drives & Motion and Motoman Robotics divisions.

Navy Lays Keel for *Colorado*

Secretary of the Navy Ray Mabus and his family look on as Annie Mabus's initials are welded onto the keel of the Virginia-*class attack submarine* USS Colorado *(SSN 788). (U.S. Navy photo by Mass Communication Specialist 2nd Class Armando Gonzales.)*

The U.S. Navy recently held a keel laying ceremony for the *Virginia*-class submarine Pre-Commissioning Unit *Colorado* (SSN 788) at General Dynamics Electric Boat.

The initials of the submarine's sponsor, Annie Mabus, were welded onto a steel plate that will be permanently affixed to the submarine. Mabus is the daughter of Secretary of the Navy Ray Mabus.

"This event marks the first major construction milestone for the submarine and helps forge a special bond between Mabus and her submarine that will last for years to come," said Rear Adm. David Johnson, program executive officer for submarines.

Construction on the *Colorado* began in March 2012. It's the fourth ship to bear the name of the state. Also, *Colorado* is the 15th submarine of the *Virginia* class and the fifth of the eight ship Block III construction contract.

Curtiss-Wright Acquires Bolt's Metallizing

Curtiss-Wright Corp., Charlotte, N.C., has acquired certain assets and liabilities of Bolt's Metallizing, Inc., Phoenix, Ariz., a provider of thermal spray coatings for critical aerospace applications, including high-velocity oxygen fuel and plasma spray coating capabilities. The business will operate within its commercial/industrial segment.

"The acquisition of Bolt's is complementary to our existing engineered coatings offerings, adding high-technology services to our surface technologies business," said David C. Adams, chairman and CEO of Curtiss-Wright Corp.

Bolt's has approximately 25 employees and generated sales of approximately $6 million in 2014. **WJ**

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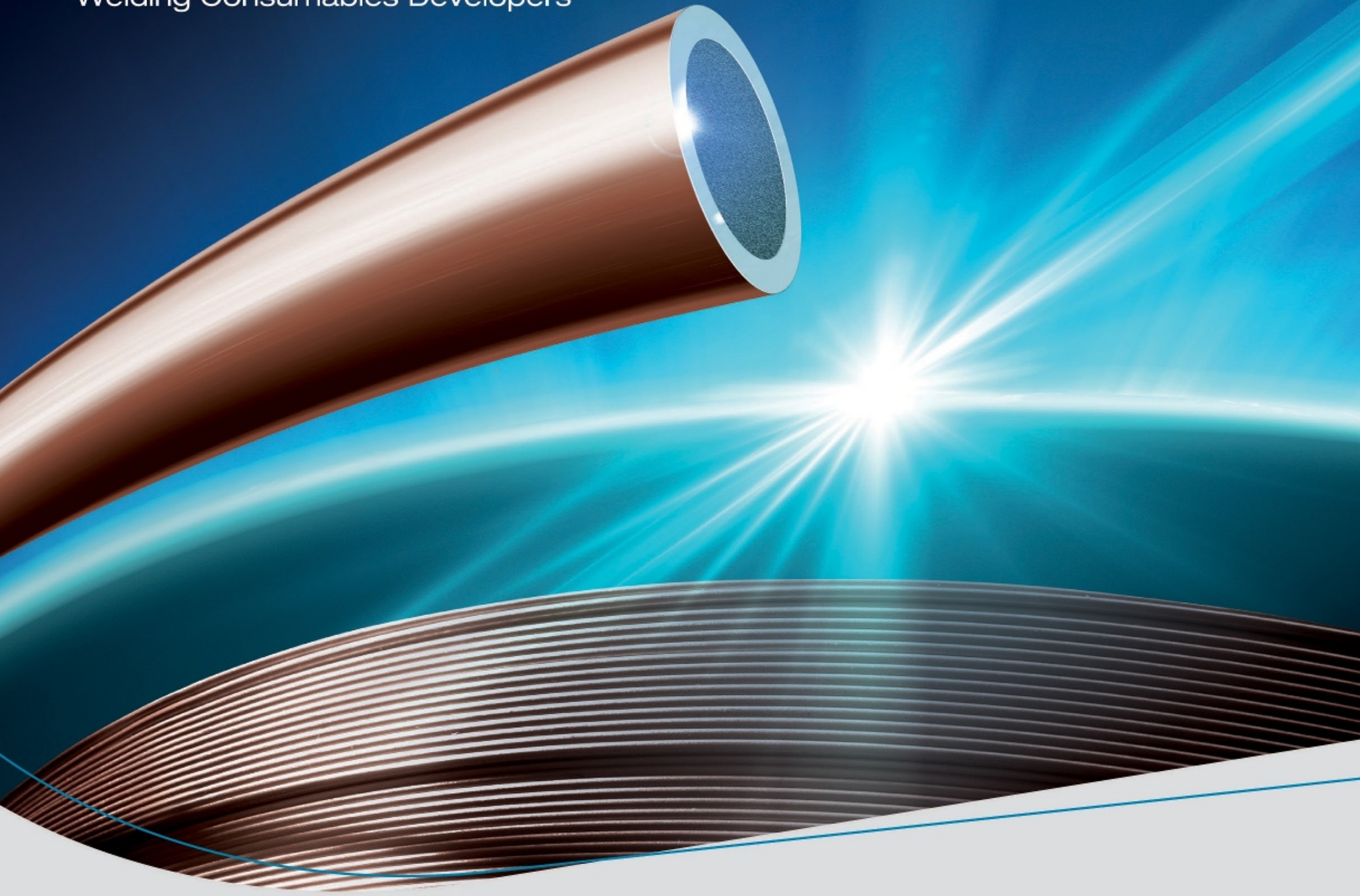

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Shipbuilding/Marine Trades Institute Offers Free Training

In March, SAMI welding students and two of their teachers posed for a group picture. From left are (first row) Dan Guertin, Jose Pestana, Rebecca Lee, Chris Bussatti, Frantz Ismee, and Instructor Matt Topper; (second row) Lead Instructor Tim Kinnaman, Bassil Brooks, Nate Menoche, Mitch McCaughey, Ben Mulligan, and Jeff St. Aubin.

Student Rebecca Lee practices her gas metal arc welding techniques.

This overhead view of SAMI's welding lab not only features students in training but also a couple of its booths and equipment/supplies.

Rhode Islanders currently have the opportunity to learn technical trades, including welding, all for free at the Shipbuilding/Marine Trades and Advanced Manufacturing Institute (SAMI). The goal is to get residents back to work using their newly acquired skills for filling in-demand, industrial careers.

Fred Santaniello, recently appointed director of Workforce Development Grants and Programs, coordinated SAMI's start. Tim Kinnaman, an American Welding Society (AWS) Certified Welding Inspector and Certified Welding Educator with 30 years of experience, is the welding division's lead instructor/program coordinator.

"A need has to be met with the shortage of skilled levels to keep the workforce going. We're doing something about providing qualified welders," Kinnaman said.

He's assisted by Instructors Matt Topper, Henry Gold, Gordon Gendron, Mark Denman, and Wray Lessard.

Developed by the New England Institute of Technology, Warwick, R.I., SAMI has received substantial start-up funds.

Last fall, the school announced it was awarded its second \$2.5 million Trade Adjustment Assistance Community College and Career Training (TAACCCT) grant from the U.S. Department of Labor. This will afford offering five new SAMI programs, including shipfitting, pipe welding, sheetmetal, pipefitting, and robotics. More than 200 residents will be served through the increased funding.

In March 2013, the school received its initial \$2.5 million TAACCCT grant, slated to train 400 SAMI participants. Also, it was awarded \$440,000 from the Governor's Workforce Board and \$50,000 from the Rhode Island Foundation.

Under Kinnaman's direction, the welding lab has been overhauled from a gutted room to a finished space with 10 booths, a fume-exhaust system, and vast array of equipment/supplies. There's also a separate classroom. These learning spaces cover approximately 4000 sq ft.

It takes eight weeks to complete SAMI's welding program that comprises 260 h and fits 10 participants per group.

Students spend 70% of their time in the lab and 30% in the classroom. Their average age is mid- to late-20s.

The curriculum covers safety; shielded metal arc, gas metal arc, gas tungsten arc, and flux cored arc welding; oxyfuel and plasma cutting; carbon arc gouging; metallurgy; welding symbols; blueprint reading; and distortion control.

Carbon steel is the primary metal utilized, but training also covers working on aluminum and stainless steel.

To make sure participants realize the quality of their welds, tests are done to see if they would pass inspections.

In addition, the students adhere to standards from ASME, AWS, and the military.

"I treat it like a job atmosphere," Kinnaman stressed. Students need to grasp that promptly showing up and being ready to perform, just like in a true work scenario, is vital. Therefore, the class clock is paid attention to, phones are not allowed, and lunch periods are timed.

This March, a new second-shift welding class began. The expectation is that these graduates will be hired by General Dynamics Electric Boat.

"There's a satisfaction with helping people do something they want to do," Kinnaman said. "If you learn your way through, and gain a career, you'll have that for the rest of your life. I enjoy seeing achievements."

So far, close to 100 welding participants have graduated. According to Kinnaman, most are hired by General Dynamics, but positions have also been acquired at boat builders on the east side of the state, along with Newport News and Bath Iron Works.

"The move to start a degree program in shipbuilding technology is also in the works, possibly a start date this fall," Kinnaman added.

And not that long ago, the Providence Business News Manufacturing Awards honored the New England Institute of Technology/SAMI for collaboration in manufacturing.

For more details, including program entry requirements, visit *samiri.org*; e-mail *info@samiri.org*; or call (401) 739-5000, ext. 3700.

— Kristin Campbell (kcampbell@aws.org)*, associate editor*

Implementing 3-D Inspection of Steel Plates Reduces Shipbuilding Costs

Gerald R. Ford *(CVN 78) is the first of a new class of aircraft carriers, the first new design since* USS Nimitz. *Redesigned from keel to mast, it will be able to launch aircraft more quickly while costing less to maintain, saving the Navy a projected $4 billion over the ship's 50-year life span.*

The Navy Metalworking Center, Johnstown, Pa., is conducting a Navy ManTech project that will develop 3-D inspection technologies to identify surface defects so they can be corrected to meet surface quality requirements before painting.

An Integrated Project Team is working with a metrology service provider to develop and modify a prototype auto-

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mated visual inspection system, plus will demonstrate it in a production environment for expected use on CVN 79, DDG 51, and LHA class ships. This team is centered on creating an inspection tool with speed, portability, accuracy, repeatability, and suitability for a shipbuilding environment.

By implementing both the prototype system and a system purchased from the metrology vendor, Newport News Shipbuilding is expected to reduce inspection costs by $4.2 million over a five-year period for construction of CVN 79.

Additionally, implementation of an inspection system at Ingalls Shipbuilding is expected to result in a $650,000 savings over a five-year period on DDG 51 and LHA class ships.

Implementation is planned on CVN 79, starting in August 2016. Secondary implementation is planned in 2016 for the preconstruction primer line at Ingalls in support of DDG 51 and LHA.

General Dynamics NASSCO and First Lady of San Diego Mark Keel Laying

General Dynamics NASSCO recently hosted a keel laying ceremony for the first ECO tanker for American Petroleum Tankers (APT) under construction at the company's shipyard in San Diego, Calif.

San Diego's First Lady, Katherine Faulconer, was the honoree for the ceremony. She authenticated the keel of the first ECO tanker for APT by welding her initials onto a steel plate that will be permanently affixed to the ship's keel and remain with the vessel throughout its service time.

San Diego Mayor Kevin Faulconer, who was also present at this event, cut the first piece of steel used to build the

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Katherine Faulconer, first lady of San Diego, practices welding at the General Dynamics NASSCO weld school inside the shipyard.

ship during the vessel's start of construction ceremony in September 2014.

The ECO tanker is the first of a five-tanker contract between General Dynamics NASSCO and APT, which calls for designing and constructing five 50,000 deadweight ton, LNG-conversion-ready product carriers with a 330,000 barrel cargo capacity.

The five-tanker APT contract, combined with NASSCO's existing backlog, will sustain its current workforce of more than 3800 and has added approximately 300 jobs.

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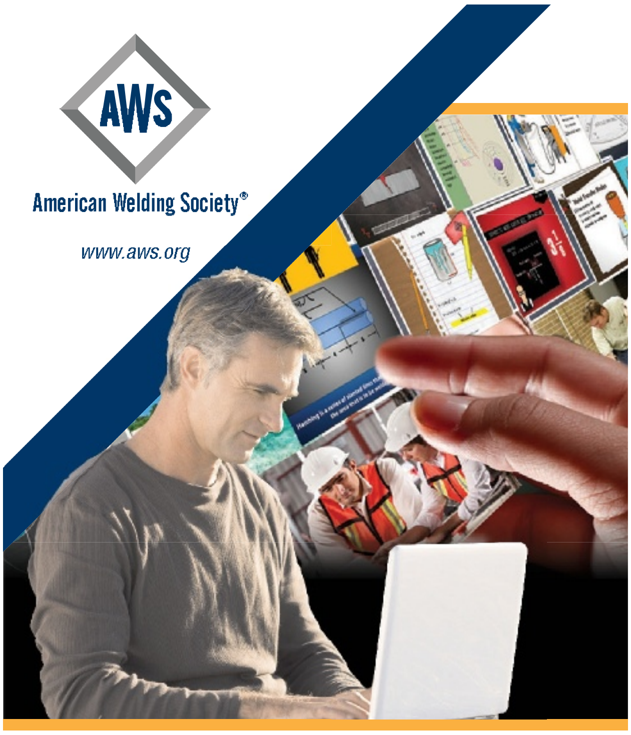

The AWS Certified Welding Inspector (CWI) is one of the industry's most recognized certifications.

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Taylor-Wharton to Design, Manufacture LNG Fuel System for *Fure West*

The 472-ft, BV-classed Fure West *is having LNG tanks installed to fuel the vessel.*

Taylor-Wharton, Minnetonka, Minn., recently revealed plans to provide an onboard LNG fuel system — including two 255 m^3 Type C storage tanks — for Sweden's Furetank Rederi AB.

Also, Furetank is seeking to comply with international environmental rules for low sulfur emissions by converting an oil and chemical cargo tanker, the 472-ft *Fure West*.

The Joint Industries Project, LNG-CONV, will convert the main engine to consume clean burning natural gas.

Taylor-Wharton will manufacture the tanks, bunkering skids, vaporization skids, and control system for *Fure West* in Kosice, Slovakia.

Weld Mold Celebrates 70 Years

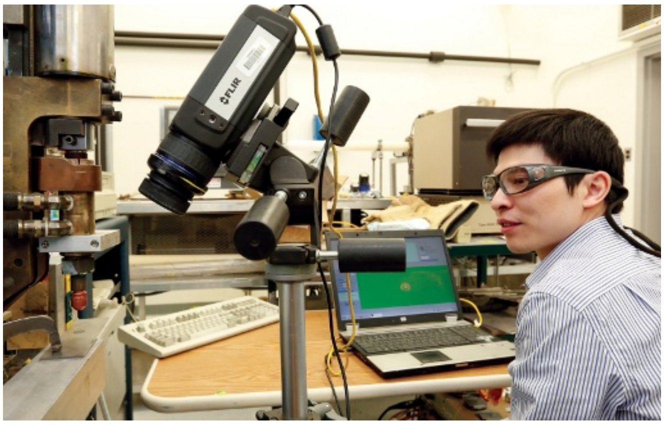
Along with developing more than 3000 systems for welding and forge welding, Weld Mold has also designed specialized machinery to facilitate forge welding, as shown above.

In 2015, Weld Mold Co., Brighton, Mich., remembers founder Matt Kiilunen and celebrates 70 years in business.

The company offers more than 3000 high-quality custom systems for welding and forge welding; specially designed machinery to facilitate forge welding; plus high-alloy welding electrodes, cored wire, and solid wire products. These range from NiCrMo and high-chrome hot work alloys to high-nickel and cobalt alloys to chrome carbide and chrome manganese alloys. Kiilunen was responsible for initiating the development of many of these products.

Darryl S. Hammock now serves as Weld Mold president. The company also has offices in China and Korea.

APLAIR Partners with ORNL to Commercialize Weld Inspection Technology



ORNL Researcher Jian Chen works with the prototype weld inspection system licensed by Tennessee-based APLAIR Manufacturing Systems.

With an aim toward automotive applications, Tennessee-based APLAIR Manufacturing Systems has licensed a weld inspection technology developed by the Department of Energy's Oak Ridge National Laboratory (ORNL). This infrared imaging system can help automakers quickly determine whether a weld is good or bad without damaging the part.

"The idea is to measure every weld, or at least every critical weld," said ORNL's Zhili Feng, one of the technology's developers. "It gives automakers an efficient method to immediately send feedback to the production lines."

APLAIR Manufacturing Systems and ORNL staff will collaborate to improve and validate the technology under a cooperative research and development agreement.

The current version of the ORNL technology can be applied to a range of steel welds regardless of the material's surface finish or thickness. ORNL researchers plan to expand the technique to other metals as well.

APLAIR intends to make a commercial product based on the ORNL technology available within two years. Currently, it has developed the plans for process validation of the systems hardware/software, and will begin building the prototype system in 2015.

Industry Notes

• **Senesco Marine Shipyard**, North Kingstown, R.I., has recently finished a deal with **Pemamek** to deliver a PEMA® welding portal for welding double bottoms and subassemblies. "We are excited about this step of automation for the shipyard and are looking forward to the relationship with PEMA as we endeavor to build quality-built vessels on time for our customers," said Michael J. Foster, vice president and general manager of Senesco. WJ

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Caterpillar Reaffirms Devotion to Illinois and Peoria as Its Global Headquarters

The construction equipment manufacturer will stay in Peoria, Ill., and build a three-tower building in the heart of a six-block site. Shown above is a rendering that reflects an aerial view from the east of the headquarters building campus.

After a multiyear study on modernizing the company's global headquarters, Caterpillar, Inc., recently reaffirmed it will remain in Peoria, Ill. The manufacturer of construction and mining equipment, diesel and natural gas engines, plus industrial gas turbines, also revealed a design that will eventually span 31 acres on the city's riverfront.

The six-block campus includes the following factors:

- The headquarters building, consisting of three office towers with parking structures below, will have sustainable design features and is sized for approximately 3200 people.
- An energy center utilizing Cat products and systems that will sustainably support the electrical, heating, and cooling demands of the campus.
- Green space, walking/biking paths, food/retail options, plus employee amenities.
- A historic equipment display across the street from the Caterpillar Visitors Center, which opened in 2012, rounds out the campus.

Illinois Governor Bruce Rauner joined Caterpillar Chairman and CEO Doug Oberhelman for the announcement. Illinois remains Caterpillar's largest concentration of employees and facilities anywhere in the world, with about 22,600 employees and two dozen facilities throughout the state.

This represents a multiyear project, starting with minor site preparation this year, but construction will not begin in 2015. Work continues with the city of Peoria on a redevelopment agreement and additional initiatives.

Lincoln Electric Reports Full Year 2014 Results

Lincoln Electric Holdings, Inc., Cleveland, Ohio, has reported net income for the twelve months ended December 31, 2014, was $254.7 million, or $3.18 per diluted share, which includes rationalization and asset impairment charges of $30.9 million and charges of $21.1 million from Venezuelan foreign exchange remeasurement losses (related to the adoption of a new foreign exchange mechanism in the first quarter). This compares with net income of $293.8 million, or $3.54 per diluted share, in 2013.

Adjusted net income was $305.9 million, or $3.82 per diluted share, compared with adjusted net income of $313.2 million, or $3.77 per diluted share, in 2013.

In addition, sales remained relatively steady at $2.8 billion in the twelve months ended December 31, 2014, vs. $2.9 billion in the comparable 2013 period. This result reflects lower volumes and unfavorable foreign exchange translation being offset by pricing actions and acquisitions.

Operating income for the twelve months ended December 31, 2014, decreased to $373.7 million, or 13.3% of sales, compared with $407.0 million, or 14.3% of sales, in the comparable 2013 period. Also, adjusted operating income was $424.9 million or 15.1% of sales, compared with $428.4 million, or 15.0% of sales in 2013.

Operating income and adjusted operating income include a $3.9 million gain, $2.5 million after-tax or $0.03 per diluted share, from an insurance settlement.

Minnesota Continues to Gain Manufacturing Jobs

For a third straight year, Minnesota gained manufacturing jobs, states the *2015 Minnesota Manufacturers Register®*, a manufacturers database and directory published by Manufacturers' News, Inc., Evanston, Ill.

According to its data, Minnesota manufacturers added 8102 industrial jobs, or 1.7% from October 2013 to 2014, outpacing the U.S. average gain in manufacturing employment for the same time period, as reported by the Labor Department.

Manufacturers' News reports Minnesota is now home to 9307 manufacturers employing 473,642 workers. Also, the publisher has recorded a 4.5% increase in the state's manufacturing jobs since October 2011, recovering 41% of the losses suffered during the recession.

Ethisphere Institute Names Hypertherm a 2015 World's Most Ethical Company

Hypertherm, Hanover, N.H., a manufacturer of plasma, laser, and waterjet cutting systems, recently announced its selection as a 2015 World's Most Ethical Company® by the Ethisphere Institute. It's one of eleven companies new to this year's list, and one of only three companies in the Machine Tools & Accessories sector.

"This honor underscores Hypertherm's commitment to meeting the highest ethical business standards and practices, ensuring long-term value to key stakeholders including our associates, customers, and communities," said Evan Smith, Hypertherm's CEO and president.

Assessment is based upon the Ethisphere Institute's Ethics Quotient™ framework to provide a means to assess an organization's performance in an objective, consistent, and standardized way. Scores are generated in five key categories — ethics and compliance, corporate citizenship and responsibility, culture of ethics, governance, and leadership, innovation, and reputation. WJ

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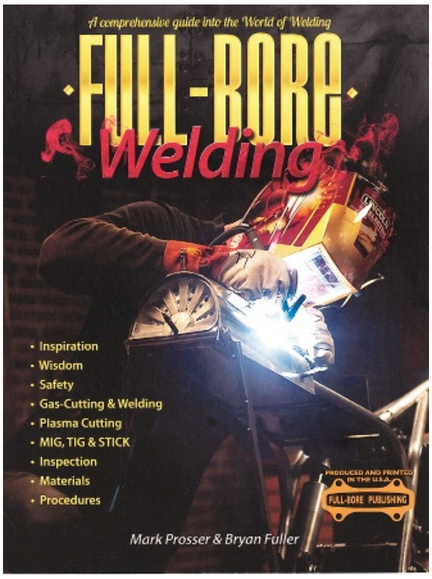
BY AUGUST F. MANZ



Full-Bore Welding, A comprehensive guide into the World of Welding, *by Mark Prosser and Bryan Fuller. ISBN 978-0-9833012-1-9. Copyright 2011. Published 2014 by Full-Bore Publishing* (fullborepublishing.com)*, Atlanta, Ga.*

This nice looking, ten chapter, softcover book with 168 pages and approximately 400 figures and photos contains a preface by Mike Rowe, star of the TV series *Dirty Jobs*. Each of the chapters — listed below — begins with a short bio, called inspiration, of someone with a career in welding.

1. Wisdom
2. Safety
3. Gas Welding and Cutting
4. Plasma Cutting
5. MIG
6. TIG
7. SMAW
8. Inspection and Testing
9. Materials
10. Welding Procedures

Every chapter ends with a conclusion that presents a series of bullets summarizing the main teachings.

The text frequently uses the personal pronoun “I.” It wasn’t until page 16 that “I” was found to be Mark Prosser. The second paragraph, on page 16, begins with “Bryan and I...” Apparently, Mark is the text author. He sprinkles the text with a lot of slang such as the following: can of worms, pull that sucker out, whack it, start whacking, fire the sucker up, and so on.

The editing could use some improvement. There are quite a number of errors and typos, such as in the note on page 31 where it refers to figure 2.17, but it really is figure 2.16. Another example is the page 62 note that refers to Fig. 4.23, when it probably should be Fig. 4.33.

Mark frequently uses the expression “stainless, steel, aluminum” as if stainless was not a steel, which it is. Most technical editors would prefer him to indicate “stainless steel, steel alloys, aluminum.”

The tank safety note on page 40, regarding if you break the neck off of a cylinder, it will cause the cylinder to easily go right through brick walls, is not true for welding gas cylinders. The true story is explained in the American Welding Society’s (AWS) *Safety and Health Fact Sheet No. 30*, which is available for a free download at *www.aws.org*. This states, in part,

“The CGA (in Pamphlet V-1) has established a 0.300 inch (7.62 mm) maximum valve inlet diameter as a requirement to minimize the propulsion effect in case the valve is severed...If the valve is broken off and the valve inlet opening meets the Compressed Gas Association (CGA) requirements, the cylinder will rapidly release all its gas (which could be a health and/or flammability concern), cause a whistling sound, and possibly spin uncontrollably...If the valve inlet opening is different...the cylinder may take off and become airborne.”

Just remember, it is good practice for all cylinders to be handled with care.

On page 75, he incorrectly defines electrode extension (stickout) as “the distance from the contact tube <tip> to the workpiece.” According to AWS, the electrode extension is the distance from the contact tube to the beginning of the arc (the arc attachment point). Stickout is the length of electrode that extends past the end of the gas cup to the arc attachment point. See AWS A3.0, *Standard Welding Terms and Definitions*, Figure B.38(A).

In addition, although the author tries to be neutral about equipment choice, it is clearly evident that his intent is to recommend Lincoln Electric products. Almost all of the equipment shown in the photographs is from that company.

Unfortunately, there is no index, so I could not locate where he defined the wiggle technique listed in the Chapter 10 procedures. I guess he really means weaving, or oscillated transversely, as defined in AWS A3.0. This is not the same as whipping, which means oscillated longitudinally.

I never did figure out what he meant by “gooping it up” in his conclusion on page 150. It is my conclusion that in spite of the number of problems and typos, welders will find this an easy-to-read, entertaining text. It has a great deal of helpful, practical information, especially when it comes to Lincoln Electric welding products. WJ

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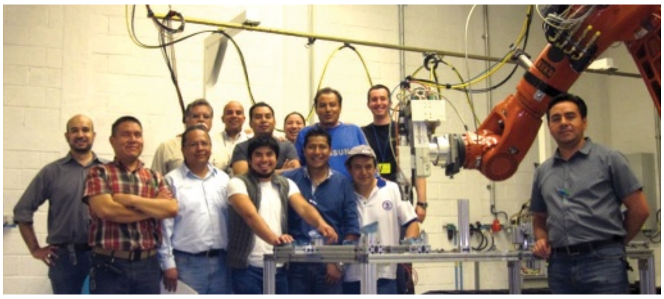
Laser Welding Training Course Organized to New EWF Guidelines



Recently, ten employees from Volkswagen, Puebla, Mexico, participated in ISQ's laser welding training course and examination.

Although the laser welding industry is experiencing a strong and consistent growth, its adoption has not been overwhelming, especially among small- and medium-sized businesses, in part due to the lack of qualified personnel with knowledge, skills, and competence in laser welding. The European Welding Federation (EWF) has engaged with laser professionals to prepare a guideline for training of laser processing personnel. The guideline is currently available for use with all countries that are EWF members, and is structured in two levels — basic and comprehensive — for laser cutting, welding, surface treatments, and processing.

Instituto de Soldadura e Qualidade (ISQ), Portugal, has recently organized a laser welding training course using these guidelines. The company prepared the course materials and ensured the availability of qualified trainers for the Instituto de Soldadura y Tecnologias de Union, the authorized training company in Mexico for this EWF laser welding cutting (ELWC) course.

A request was received from a Volkswagen plant in Puebla, Mexico, for training and qualification of laser welding personnel, representing the first time EWF's laser welding personnel guideline has been used outside of Europe.

Ten Volkswagen trainees, from different departments including welding quality control, maintenance, and line production welding engineers, were trained and passed the examination. Beatriz Adriana Martinez Betanzos, one of the trainees, said, "Having the ELWC training has given us a sea of possibilities to improve our competitiveness and tools to boost quality in our cars."

GE Will Supply 2.6 GW of Electricity to Power Homes in Egypt

General Electric (GE) has signed contracts with the Egyptian government to deliver 2.683 GW of electricity, equivalent to the energy needed to power more than 2.5 million homes. GE will supply a total of 46 turbines — 34 aeroderivative and 12 heavy-duty gas turbines — that will begin to deliver power as soon as this month. The contracts, which were announced in March at the Egypt Economic Development Conference, were signed in December 2014.

"We are building on our 40 years of supporting Egypt and proud to be bringing 2.6 GW of critical, multimodal power in support of the Egyptian Power Boost Program," said Steve Bolze, president and CEO, GE Power and Water. "We are making great progress in Egypt on the build out, and it will be one of the fastest project executions of this scale in our history."

This past December, GE dispatched its gas turbine technology to construction sites across Egypt within hours of signing contracts with the government. Currently, GE's gas turbines help generate more than 9.5 GW of electricity in Egypt, nearly 30% of the country's total installed capacity.

Carnival Launches First of Two New Ships in 2015

Carnival Corp. & plc recently unveiled the Britannia*, its newest ship, at a naming ceremony in Southampton, England.*

Carnival Corp. & plc, a cruise company with brands in North America, Europe, Australia, and Asia, recently celebrated the launch of P&O Cruises UK's newest ship, *Britannia*, in a naming ceremony held in Southampton, England, to commemorate its entry into service for the P&O Cruises fleet. The 143,000-ton ship is the first of two that will be joining Carnival Corp.'s fleet in 2015. Among those in attendance at the naming ceremony were Carnival Corp. President and CEO Arnold Donald, Carnival UK Chairman David Dingle, and Carnival UK CEO David Noyes, along with distinguished guests, government officials, and the ship's crew.

Britannia will be joined later this year by *AIDAprima*, the new flagship vessel for Carnival Corp.'s Aida brand, when it begins regular service this fall. It will be the company's most environmentally friendly cruise ship to date. The 124,100-ton vessel will accomodate 3300 passengers.

In addition to new ships, Carnival Corp. continues to expand its fleet with upgrades and refurbishments to existing ships. In 2015, the company plans to upgrade or refurbish 17 ships across six of its brands.

New Joint Venture Company to Produce Large-Diameter Welded Pipes

Japanese steelmaker JFE Steel Corp., Japan-based Marubeni-Itochu Steel, Inc., and Senaat GHC, a private joint-stock general-holding company owned by the Emirate of Abu Dhabi government, have announced an agreement to establish a joint venture company in Abu Dhabi called Al Gharbia Pipe Co., to manufacture and sell large-diameter welded steel pipes, mainly for the energy industry. Production is expected to begin in October 2018.

Al Gharbia Pipe Co. will manufacture and sell high-grade, large-diameter steel pipes to energy companies in Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates, with an annual production capacity of 240,000 tons and an approximate investment of $300 million. WJ

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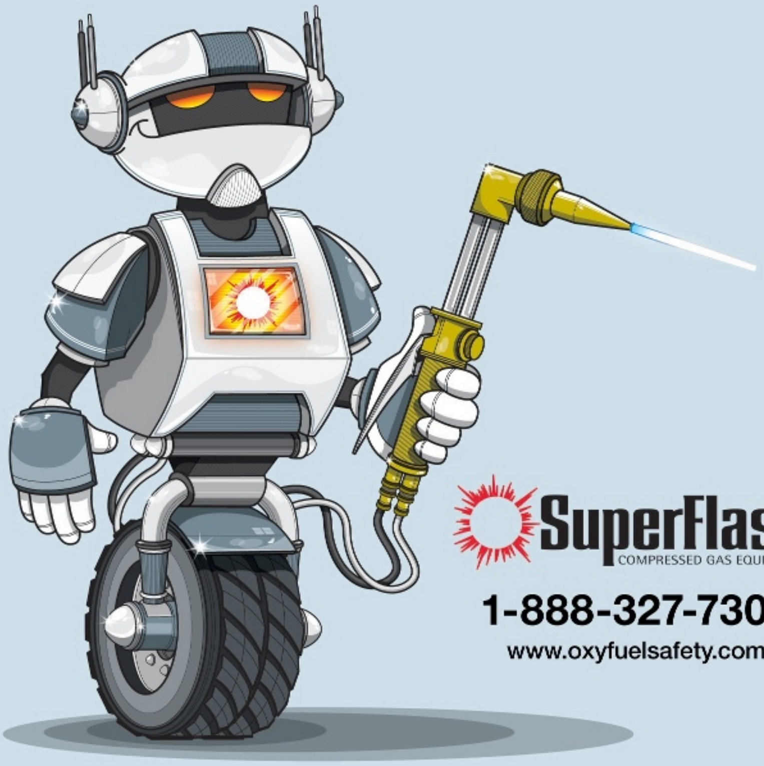

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STAINLESS Q&A

BY DAMIAN J. KOTECKI

Q: Our client has difficulty passing a fillet weld test welding 2205 to 316L stainless steel using 316L GTAW rod. The macros show lack of penetration at the root in both of two procedure tests. The parameters are reasonable based on our references: 205 A, 13 V, and 5.4–6.2 in./min. We believe the likely cause is welder technique. Would they be any better off with 2209 consumable with respect to penetration? I expect not, but the fabricator is clearly frustrated, and we would like to find a solution.

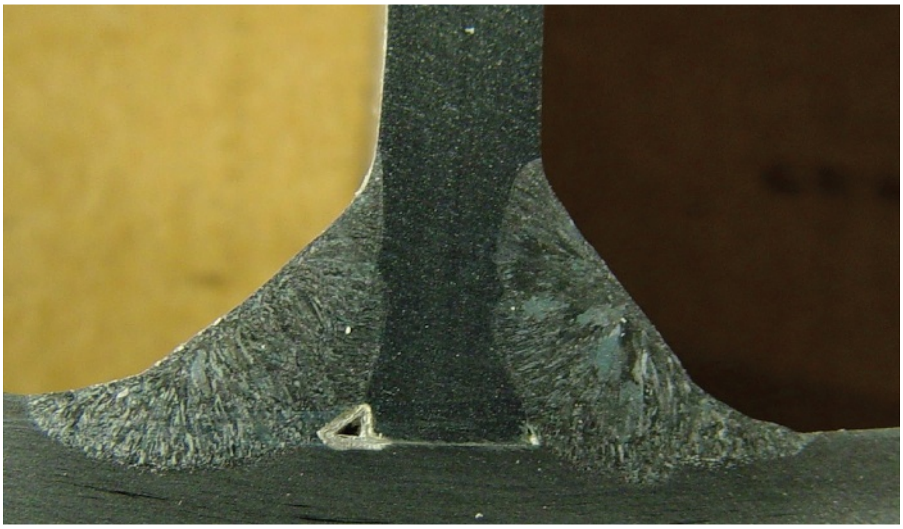

Fig. 1 — Fillet weld showing incomplete GTAW root penetration.

A: Figure 1 shows the fillet weld cross section provided. The lack of root penetration is clearly evident on both sides of the weldment. Changing to 2209 filler metal seems unlikely to have had any significant effect on the root penetration. Based on the concave bead profile evident in Fig. 1 on both sides of the weldment, the welder's technique indeed seems to be the probable cause of the lack of root penetration.

It seems likely that the welder was much more frequently using GMAW than GTAW. In GMAW, welders most often use a forehand welding technique, also known as "pushing the puddle," a nonstandard term for "pushing the weld pool." In this tech-

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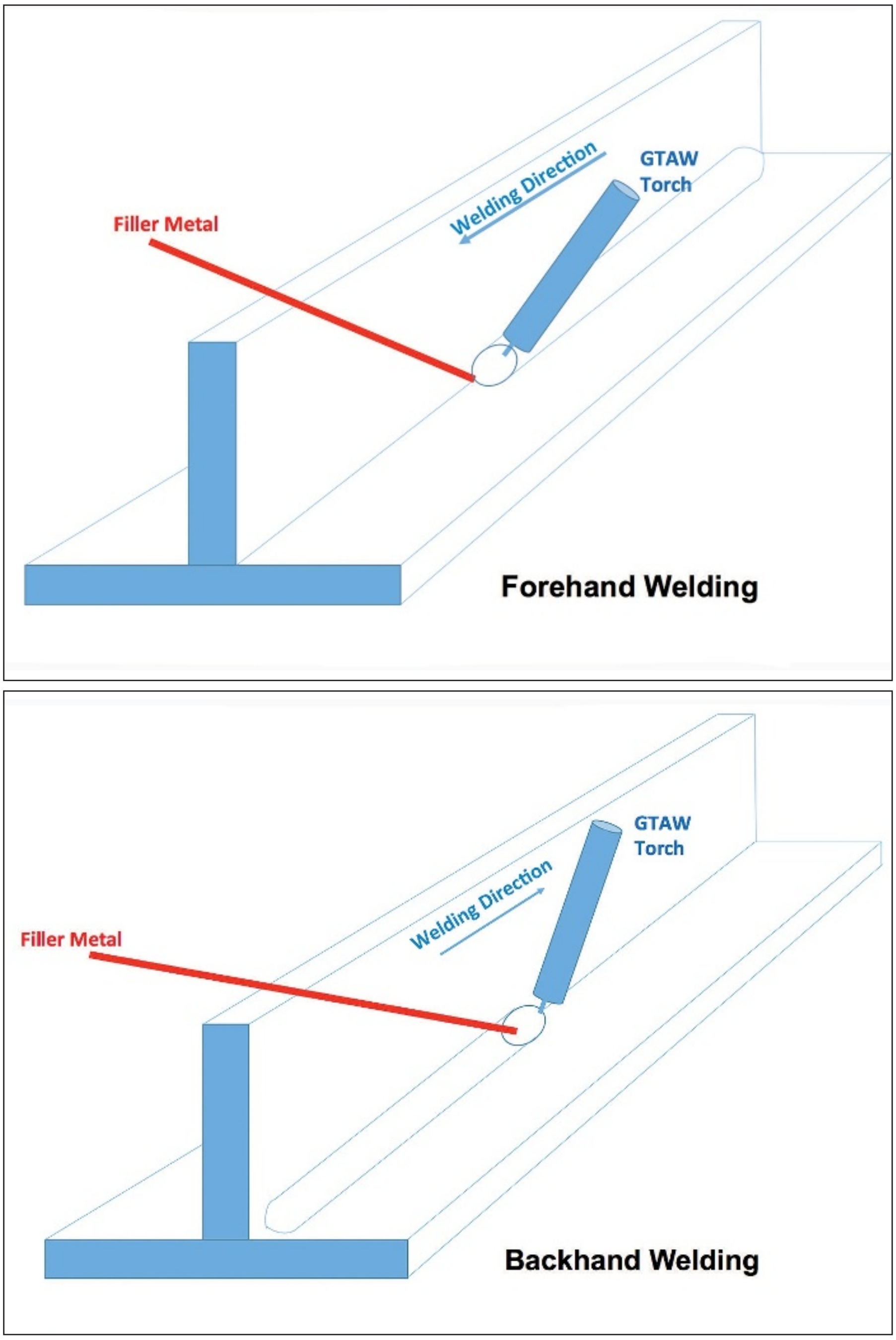

Fig. 2 — Schematic of forehand vs. backhand GTAW.

nique, the torch is inclined in the direction of weld progression. In GMAW, this technique generally produces a slightly concave fillet weld profile. The root penetration is adequate unless an excessively large pool is pushed, in which case the leading edge of the weld pool may roll over and bridge across the root, preventing root penetration. Lack of root penetration is seldom a problem in GMAW fillet welds.

In GTAW, the forehand technique involves dipping the filler metal into the weld pool at the leading edge of the weld pool. There, the filler metal has a tendency to bridge over the root, preventing root penetration. As in GMAW, GTAW with a forehand technique tends to produce a somewhat concave weld profile, which is a tip-off that this technique was used for the welds shown in Fig. 1. It was suspected that the welder carried over the forehand technique from GMAW to the GTAW welds under consideration.

On the other hand, GTAW by the backhand technique, also known as "pulling the puddle," positions the welding torch so that it is inclined away from the direction of welding. In the backhand technique, the arc is directed at the leading edge of the weld pool and at the root, while the filler metal is dipped into the weld pool at the trailing edge of the weld pool. There is no tendency to bridge the root, and the weld profile tends to be flat or slightly convex.

Figure 2 shows schematic drawings of the forehand technique and the backhand technique, in both cases as the welder would hold the torch right-handed. Note the inclination of the torch in each case and the point of entry of the filler metal into the weld pool.

Following this suggestion, the inquirer investigated and found that the welder had indeed been using the forehand technique. The welder was instructed to repeat the procedure qualification by using the backhand technique. The new procedure qualification successfully produced root penetration.

It is interesting to note that AWS B2.1/B2.1M:2014, *Specification for Welding Procedure and Performance Qualification*, does not include forehand technique vs. backhand technique as a variable in the list of data to be included in a Welding Procedure Specification (WPS) according to Clause 4.13. Neither does that specification include forehand vs. backhand technique in the list of procedure qualification variables for a Procedure Qualification Record (PQR) according to Clause 4.14. Perhaps that specification should include forehand vs. backhand technique as an essential variable. WJ

DAMIAN J. KOTECKI is president, Damian Kotecki Welding Consultants, Inc., a member of the A5D Subcommittee on Stainless Steel Filler Metals, D1K Subcommittee on Stainless Steel Structural Welding, WRC Subcommittee on Welding Stainless Steels and Nickel-Base Alloys, past chair of A5 Committee on Filler Metals and Allied Materials, and AWS president (2005–2006). Send questions to damian@damiankotecki.com, *or mail to Dr. Kotecki, c/o Welding Journal Dept., 8669 NW 36 St., # 130, Miami, FL 33166.*

BY ROGER HIRSCH

Q: Our company spot welds a lot of weld nuts on channels. We had a lot of trouble with getting good strength until our welding foreman increased weld time. Now we have acceptable strength in the welds. But my quality control department tells me that the thread on these weld nuts will not pass the go/no go test. What are we doing wrong?

A: The mistake is increasing welding time to increase weld strength. Because the welding current is conducting through the body of the weld nut, adding more time just heats the body of the nut and makes it somewhat plastic. The force from the electrode now compresses the nut slightly and changes the thread pitch. This causes the go/no go test failure.

The solution is to reduce the welding time as low as possible and increase the heat. This makes the projections on the weld nut heat faster so they fuse without excessively heating the body of the nut. The overall idea is to heat the projections quickly and not the body of the nut.

One other possible cause of a change in thread pitch is the use of a low electrode force. This causes the contact point under the electrodes to heat higher than desired and create the plastic state of the metal. While it sounds counterintuitive, increasing the force can reduce the compression of the nut if weld time is reduced and weld heat is increased.

Q: We have a 150-kVA press welding machine that was purchased new about ten years ago. When it was new, we were able to weld two sheets of 10-gauge mild steel without any problem. Over the years, we have had to increase the weld heat to maintain good welds. Now we are at 99% and cannot get consistently good welds without lowering the electrode force. Unfortunately, when we lower this force, metal flies out in all directions and the electrodes have to be cleaned quite often. What could cause this slow loss of power over time?

A: The solution can be in many areas. But the most probable is in the welding transformer secondary copper. While copper is an excellent conductor, the places where the copper parts on the secondary of your transformer are bolted together can oxidize over time. This oxide has a much higher electrical resistance than the bare copper. Each bolted joint drops some voltage to reduce the available voltage needed to do your weld, causing the lower heat issue.

The solution is to remove all of the bolted joints starting at the welding transformer's front copper pads. Figure 1 shows a typical joint. Inspect these joints. If they are just slightly discolored and not showing large areas of melting or high spots, you can clean them with a 3M Scotch-Brite™ pad. The red Scotch-Brite™ pads work best for this. Never use emery cloth or oth-

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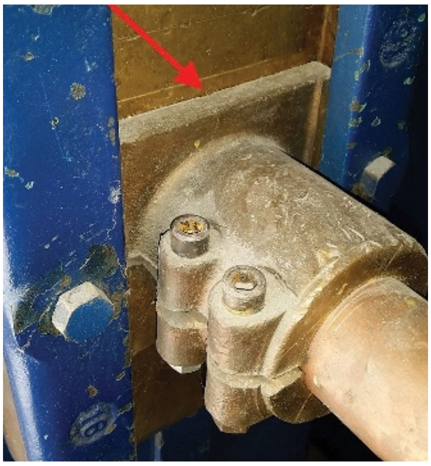

Fig. 1 — The transformer front copper pad needs to be unbolted and cleaned.

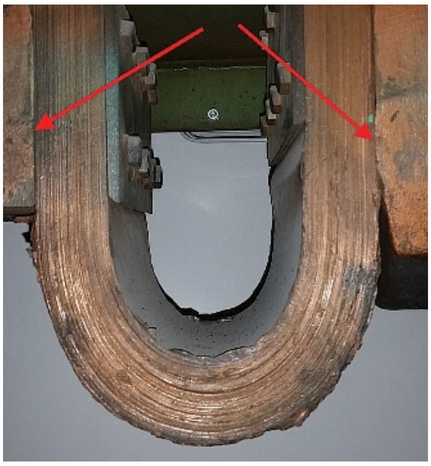

Fig. 2 — Laminated shunt. Check and clean all copper-to-copper contact areas.

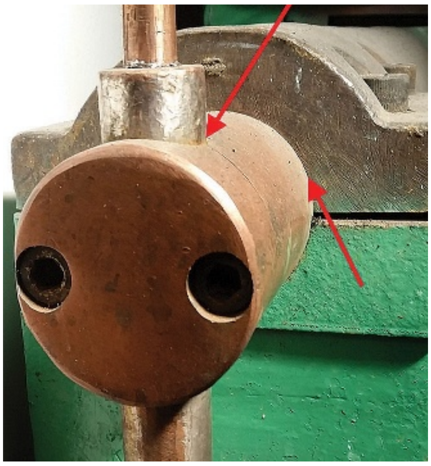

Fig. 3 — Check areas where water-cooled holders are clamped into the welding arm and where the arm is clamped to the copper conductor from the machine's transformer.

er abrasives since they cause grooves in the surface that reduce the available conducting areas.

Once the surfaces are clean, apply a coating of silver on both sides of each joint. A good product for this is Cool-Amp. This is a silver powder that is available from most arc welding supply houses. To use, dip a soft cloth into clean water, then dip into the Cool-Amp powder. Rub the powder across the surface several times. Let the part set for at least two minutes and then buff it with a soft cloth. Repeat layers until you see what looks like a dull silver color.

If the surfaces show arc points that are not flat, they will have to be machined professionally. This should only be done if more than 25% of the surface is bad. Use the silver process above when finished.

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Another thing to look at is the condition of the shunts. On most welding machines, the secondary current is conducted from the transformer to the upper moving part of the machine through a stack of flexible thin copper sheets called a laminated shunt — Fig. 2. Over years of use, these pieces of copper break off near the fastening points, which reduces the number of sheets left for conducting the welding current. If you find that more than 5% of the sheets have broken off, replace the shunts. They are not expensive, and your resistance welding equipment supplier can take the measurements to get an exact, and probably improved, laminated shunt.

Don't forget to check the areas where the electrode holders attach to the welding machine's arms — Fig. 3. It is not unusual to see a holder that has been smashed with a hammer during "adjustment," and then that portion of rough surface is pushed lower into the arm to conduct electricity. Remove the electrode holders and check for smooth and clean surfaces. If the holders are beat up, just replace them. The new ones are not very expensive, and you will gain both power as well as eliminate water leakage where the electrode is installed.

Once you do this cleaning and reassembling, the welding machine will probably put out 20% or more power than it did before the cleaning with the same heat settings.

Q: We have only one spot welding machine in our plant. It was originally purchased to weld 12-gauge channels. We no longer have that job but have recently taken in a new project welding 22-gauge steel panels and drawers together. The problem is that the machine is too large and we have to set our weld heat at about 30% to get a weld that does not send metal out into the aisles. And at this low heat setting, our window of good and bad welds is very small. Just a little change in electrode force or weld heat can produce a weld that snaps off without making a good nugget. What can we do?

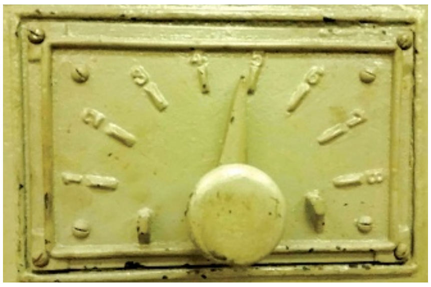

Fig. 4 — Adjust the tap switch to set the main range of weld heat.

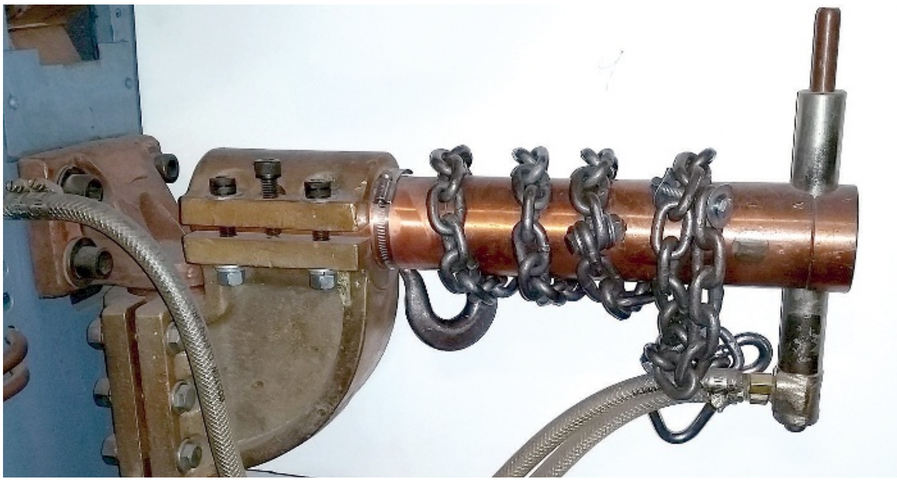

Fig. 5 — Ancient heat adjustment using chains before electronic welding controls were available.

A: Unfortunately, the "one size fits all" idea does not work well with resistance welding machines. But here are some suggestions. First, see if your machine has a large tap switch handle — Fig. 4. This will be either on the side of the machine, or might be mounted to the welding transformer itself. The tap switch reduces the secondary voltage of the welding transformer to lower the current. Setting this tap switch to a lower number will lower the welding current. This should allow you to make better welds on thinner metal by keeping the weld heat setting no lower than 60%. If you are welding thicker metal and require a weld heat greater than 90%, turn the tap switch to a higher number and reset the weld heat.

Unfortunately, some of the newer resistance welding machines do not have tap switches. The transformer manufacturers may have thought it was a good idea to eliminate these tap switches. It was not.

But you might find that there are internal terminals to lower the secondary voltage in the back wiring compartment of the welding transformer. First, turn off the power going to the welding machine and lock-out the disconnect switch. Then take the back plate off the welding transformer and see if there are some large studs inside. If there are, they will probably be marked with numbers. The lower number will be the lower heat. Just unbolt the wire attached to a higher number stud and bolt it to a stud with a lower number.

If your welding transformer does not have these studs and has only one heat setting, the only other choice is to operate the welding machine on a lower line voltage. If the machine is rated at 440–460 V, you can connect it to a 220-V line if you have one large enough. The machine will now have about one-half the secondary current, and you will be able to set your control to a much higher welding heat setting to provide a more robust and stable weld process.

Fun Fact: In the early days of resistance welding equipment, before electronic welding controls, some welding machines were supplied with two tap switches that had eight positions on each switch. This allowed for up to 64 different heat settings.

And even earlier than this, operators wrapped heavy metal chains around the lower welding machine arm to lower the welding heat — Fig. 5. This changed the impedance of the welding machine secondary. The more turns of chain, the lower the heat. The downside was that the chains became very hot during production welding. WJ

ROGER HIRSCH is a past chair of the RWMA (Resistance Welding Manufacturing Alliance), a standing committee of the American Welding Society, and president of Unitrol Electronics, Inc., Northbrook, Ill.

Mail your comments and questions to Roger Hirsch, c/o Welding Journal, 8669 NW 36 St., # 130, Miami, FL 33166; or e-mail roger@unitrol-electronics.com.

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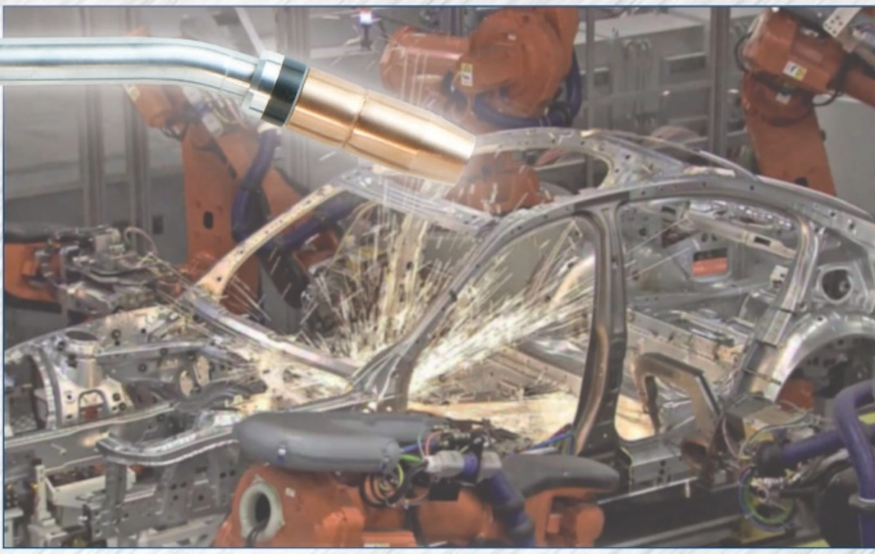

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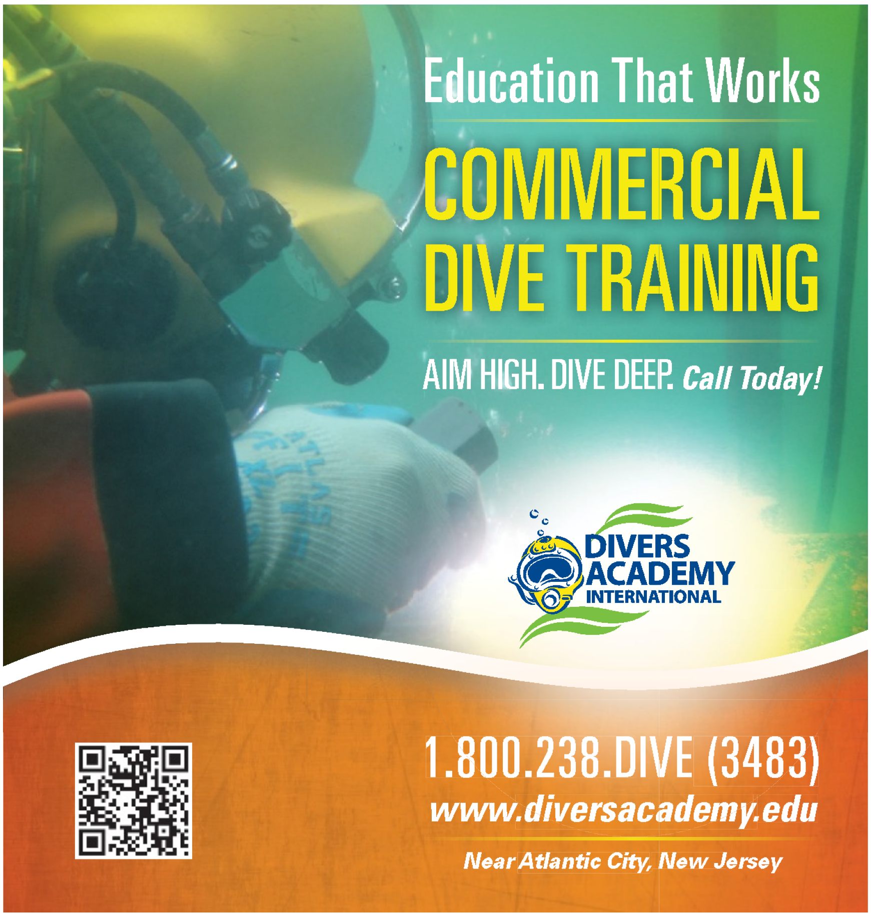

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Shipbuilder Solves Stud Welding Problem

BY STEVE BLEVINS

By eliminating the problem of erratic flash caused by arc blow, a shipyard now saves two labor hours on every manhole welded

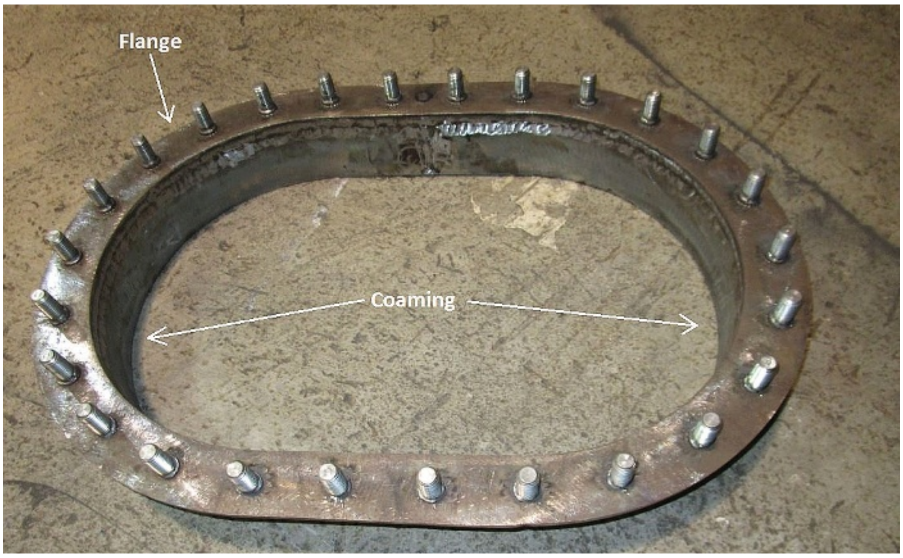

Fig. 1 — An example of a typical manhole.

In shipbuilding, there are many applications for stud welding. Some of its various uses include pins for insulation, cable and wire hanging, scaffolding supports, and manholes. In most instances, there are no problems with stud welding since many studs are shot on large-size paneling. However, there are times when defects occur with stud welding, such as flash that is visually unacceptable. When this occurs, the rework includes grinding the stud off, cleaning the plate, then reshooting the stud — greatly increasing the time, labor, and material costs of the operation.

A manhole is defined as "an opening, often with a cover, through which a person can enter a sewer, conduit, ship's tank, etc., for repair work or inspection" (Ref. 1). A manhole can consist of just the flange portion welded onto the hole; others are raised, as shown in Fig. 1. Depending on size, a ship may have hundreds of manholes and manhole-type structures.

The Problem

Ingalls Shipbuilding had a persistent problem with unacceptable flash on the manhole flanges, especially when using ⅝-in.-diameter studs.

Visual inspection determined that the cause of the flash was magnetic arc blow. Magnetic arc blow occurs when there is an uneven mass of magnetic material near the weld arc. As a result, the molten metal is pulled away from edges and attracted toward the larger or closer magnetic mass. This magnetic attraction causes an uneven flash around the base of welded studs. The effect is shown in Fig. 2. In Fig. 2, this side view shows how the arc was pulled away from the center of the stud and attracted toward the standing tube portion of the manhole (called a coaming). The coaming, in this case, acted like a magnet to pull the arc and flash toward it, resulting in the arc blow.

The lift of the stud welding gun and the plunge were checked to verify they were at the proper settings. After the gun settings were determined to be correct, five studs were shot on scrap plate to ensure that the welded studs were visually acceptable and mechanically adequate by performing bend tests. This test requires the studs be bent to a 15-deg angle, then returned to 90 deg. It is not to be performed on production studs (Refs. 2, 3).

Since arc blow is proportional to current intensity, they tried reducing the current to the minimum that would produce an acceptable weld flash. When that proved unsuccessful, other remedies were tried to minimize arc blow, including varying the placement of ground clamps around the manhole in an attempt to balance out the arc, positioning the stud welding gun cable to induce arc blow away from the coaming, and placing a magnetic mass on the outer edge of the manhole close to each stud. None of these strategies worked and arc blow still occurred.

Using an Inverter-Based Power Source

The solution to the flash problem was eventually found when they tried an inverter-based stud welding power source. One feature of this type of power source is it can be set for the various stud welding positions. When vertical stud welding, the operator can set the machine to "Vertical." Initially, the machine was tried using the "Down Hand" setting. The appropriate current and time settings were used per Ingalls Shipbuilding internal procedures. After the machine was set, visual inspection and mechanical testing were performed to ensure the settings worked (there were no visual discrepancies regarding flash on the scrap plate). Afterward, when stud welding on manholes was performed, the same problem of arc blow occurred, just like when the older power source was used.

Once again, the standard remedies were tried with the inverter power source with unsuccessful results.

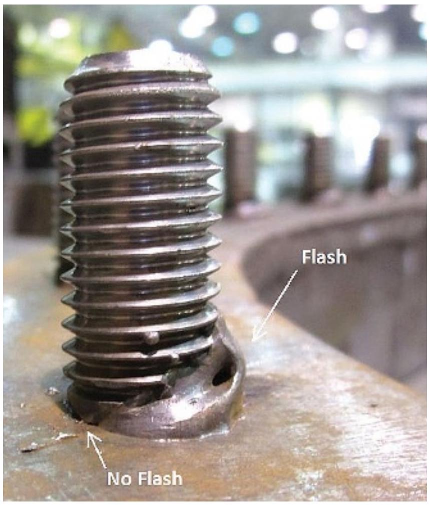

Fig. 2 — An example of the effect of arc blow.

The Solution

Earlier, the author had witnessed vertical studs shot using an inverter power source. Even though standard ceramic ferrules were used, the studs had a full 360-deg flash and there was no weld flash pulled down on the bottom portion, which is typically seen when shooting studs in a vertical position. Because of this, the idea to use the "Vertical" setting when welding down-hand studs on a manhole was attempted. The result was a full 360-deg flash, as shown in Fig. 3.

Many studs were shot on numerous manholes using this setting and the method consistently produced a full flash. Note: the power source produced the same results when set to either the "Overhead" or the "Vertical" setting.

The inverter technology improved the visual acceptance of the studs due to the arc-stiffening and stabilizing capability for out-of-position stud welding provided by the 60 kHz frequency. The high frequency helps maintain the correct arc path by keeping the arc tighter and more focused during welding, achieving a full flash. Although using the out-of-position settings greatly helped with the flash, it was discovered that not just any standard ferrule could be used. The best results came from using ferrules with a cavity diameter just fractions of an inch larger than the upper inside diameter of the ferrule (the difference in diameters being nearly 0.02 in.). To ensure that it was not just the ferrules that made a difference, the preferred ferrules were used with an older, noninverter unit and arc blow still resulted. As a result of using the out-of-position settings and the proper ferrules, it was originally estimated that this method will save two labor hours per manhole. Since every ship has numerous manholes with studs welded onto them, the cost savings on rework and material waste alone are significant.

Conclusions

Magnetic arc blow can be a common occurrence when welding studs near an edge or regions that have an increase in mass. Several methods exist to minimize arc blow when using a standard stud welding power source, but they may not be reliable or consistent. Any inverter-based stud welding power source that has arc-stabilizing and stiffening capabilities for out-of-position welding should be tried to solve magnetic arc blow problems, regardless of industry.

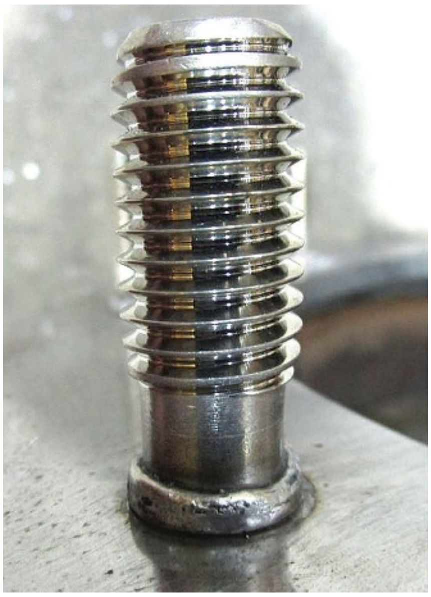

Fig. 3 — An example of a stud weld with full flash.

Acknowledgment

The author wishes to thank Clark Champney of Nelson® Stud Welding for guidance on technical matters regarding arc blow and arc stability. WJ

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Getting Ready for WorldSkills São Paulo 2015

Representatives from AWS and industry discussed with WorldSkills management ways to cooperate in the upcoming competition

BY KRISTIN CAMPBELL

Andrew Cardin Prepares to Compete Alongside the World's Best Welders

Second time is really the charm for Andrew Cardin of Sutton, Mass. After placing as runner-up in the preselection process for the 42nd WorldSkills Competition, he wasn't ready to hang up his welding helmet and gloves.

Now, his hard work has paid off. Cardin has earned the honor of representing the United States this year as its welding competitor at the 43rd WorldSkills Competition to be held August 11–16 in São Paulo, Brazil.

"This has been the ultimate goal in all the years I have been training," Cardin said. "I have based almost all of my financial and career decisions off of how it would affect my end goal of hopefully representing in WorldSkills."

By achieving this top spot, he has also earned a $40,000 four-year scholarship from the AWS Foundation sponsored by Miller Electric.

Winning the AWS Competition

Recently, Cardin won the AWS International Final Weld Off organized by the AWS Skills Competition Committee, earning him the recognition as the U.S. welding contestant at WorldSkills — Figs. 1, 2.

This event took place February 23–25 at the Alabama Robotics Technology Park in Huntsville, Ala.

Over 18 hours, a series of four projects was completed, including test coupons on 8-mm, 10-mm, and 12-mm plates, and schedule 80 pipe; a pressure vessel; a stainless steel project; and an aluminum project.

Josiah Mechaelsen of Melrose, Minn., placed second. He trains at Alexandria Technical and Community College, plus has held positions from welding traps to being a machinist.

Jacob Miller of Greers Ferry, Ark., placed third. At a recent ASU-Heber Springs reception, he was honored with a Senate Citation and day named on his behalf in Cleburne County.

These three contestants were selected as the finalists at the AWS U.S. Invitational Weld Trials during FABTECH 2014.

Australia and Canada were also represented at this Weld Off competition. National champion welders Kallon McVicar and Tommy St-Martin, respectively, received participation plaques and will represent their countries at WorldSkills São Paulo 2015.

Keeping Calm and Welding On

To prepare for the upcoming world contest, Cardin is training full-time. He mainly follows the same routine developed through years of discipline.

"I try to assign each day in a week to focus and improve or maintain one process, doing one joint in all positions. This requires a lot of patience; running through different trials to be able to meet the criteria every time you strike an arc, no matter the process, position, or joint configuration," Cardin said.

According to the WorldSkills website, at the competition, the contestant will be judged on his or her ability to weld butt-joint and fillet welds of plates and pipes in all working posi-

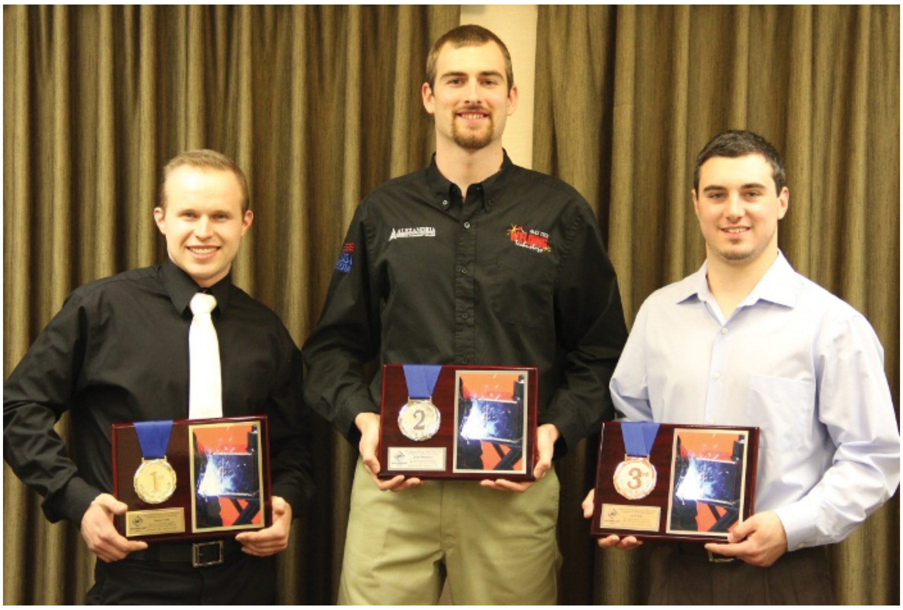

Fig. 1 — The AWS International Final Weld Off competitors discovered the results at an awards banquet on February 26. In order of first, second, and third are (from left) Andrew Cardin, Josiah Mechaelsen, and Jacob Miller.

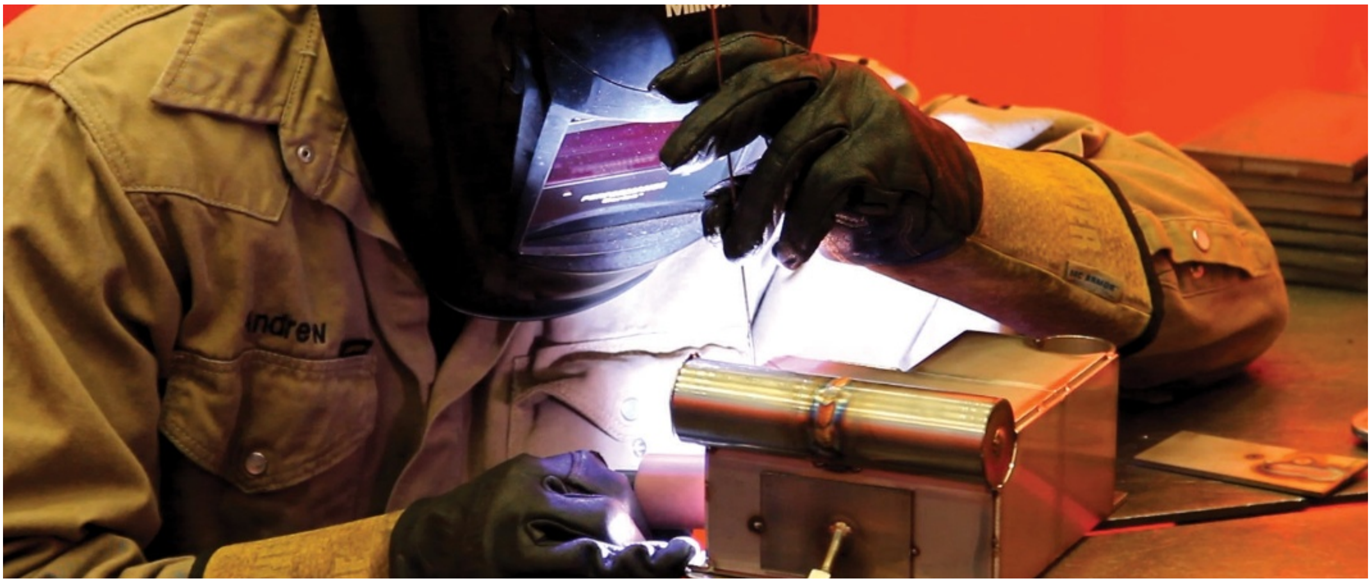

Fig. 2 — Andrew Cardin is pictured here participating during the AWS International Final Weld Off. "I feel more accomplished than an Olympian, because once I am done with competing, my skill will be the base of my career path for life," he said.

tions at different angles of inclination and rotation to be completed within a given time frame. Weldments will be nondestructively tested to specific assessment criteria and scored accordingly.

Cardin feels fortunate to have a loyal team. "At no point could I have ever produced this victory by my own determination or willpower," he said.

He graduated from Blackstone Valley Technical High School in 2011. Dan Rivera has not only served as his welding instructor for seven years, but also introduced him to entering the competitive arena. Cardin's father allows him to train in the home basement while his mother and siblings Rachael, Jessie, and Joseph have been very supportive. Many other individuals have positively impacted him, too. Companies have provided needed equipment, supplies, and material/cutting services.

Hope for What's Yet to Come

"As soon as I am back from São Paulo, the sky is the limit," Cardin said in relation to the future.

He's interested in pipe welding and working in different locations, including the oil fields of Australia, off the Gulf Coast on an oil rig, or power plants across the country.

"These jobs allow me to work three weeks on and have two to three weeks off. This is the time I would take to use my $40,000 scholarship and work on getting my teaching degree," Cardin explained. "As much as I love welding, I know that I will want to teach it someday when I don't want to travel anymore and want to share my passion with others." WJ

Welding Side of WorldSkills Competition Addressed at AWS Gathering

The American Welding Society (AWS), Miami, Fla., recently hosted two distinguished guests from WorldSkills International, CEO David Hoey with Sponsorship and Partnership Director Alexander Amiri, on March 18 at its world headquarters.

Following the meeting, AWS increased its participation level to be a Global Industry Partner of WorldSkills International, a not-for-profit membership association open to agencies or bodies that promote vocational education and training in their respective countries/regions.

"We're thrilled to be a part of WorldSkills," said AWS Executive Director Ray Shook.

The 43rd WorldSkills Competition, set to take place this year in São Paulo, Brazil, from August 11 to 16 (*www.worldskillssaopaulo2015.com*), will be the first time this event is held in Latin America. It's expected to attract around 1000 competitors, including SkillsUSA's team of 19 contestants, and draw 200,000 visitors.

Held every two years in a different host country, the contest enables top young adults from across the globe to test their abilities in many skills, including welding. Gold, silver, and bronze medals are awarded to winners.

AWS Corporate Director, International Sales, Jeff Kamentz reviewed the Society's history, global reach, growth, departments, and FABTECH and Weldmex shows.

"This partnership is an interactive program, and on behalf of AWS, it's a conscious effort to be involved," Kamentz said.

AWS Foundation Executive Director Sam Gentry spoke about scholarships, the Careers in Welding Trailer, Boy Scouts

Posing for a group shot (from left) are WorldSkills CEO David Hoey, AWS Executive Director Ray Shook, AWS Director of Marketing Lorena Cora, AWS Foundation Executive Director Sam Gentry, AWS Director of Conventions and Meeting Services Matt Rubin, WorldSkills Sponsorship and Partnership Director Alexander Amiri, and AWS Corporate Director, International Sales, Jeff Kamentz.

of America welding merit badge, and career materials offered.

Hoey addressed several factors on WorldSkills, including its mission to raise the profile and recognition of skilled people, and show how important skills are in achieving economic growth and personal success. He detailed its six key focus areas; more than 70 member countries and regions (in the U.S., the member organization is SkillsUSA); and an example where WorldSkills winners used their trades for a good cause in South Africa with the Sanitation Studio program.

“Skills competitions is the unique thing we do,” Hoey said. “There’s a gap with moving from competence to excellence. It’s about benchmarking your performance against international standards. It’s a showcase of careers and changing people’s minds.”

Amiri brought up the importance of international collaboration. Over the course of six days, new relationships can be created.

Lincoln Electric’s Director of Technical Training, Carl Peters, participated remotely in the meeting. He detailed the company’s origins behind joining WorldSkills as a Global Industry Partner along with providing equipment, consumables, and fume extraction. He also discussed the benefits of AWS and Lincoln Electric uniting to work on future welding competitions at WorldSkills.

“Together, we have a better offering to the world. We can open up doors. Why do it individually?” Peters said.

The meeting also focused on opportunities at WorldSkills São Paulo 2015, including in the welding pavilion, cyber cafe, try a skill area, and village.

Ideas for youth interaction and engagement included setting up a chocolate welding activity; having virtual welding machines; and producing a paper welding mask that can be assembled by following directions.

The following factors were examined as well: visibility/branding efforts and suggestions for helping CNI, the National Confederation of Industry Brazil, perhaps by making presentations showing 3D models of various skills.

KRISTIN CAMPBELL (kcampbell@aws.org) *is associate editor of the* Welding Journal.

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Improved Welding of Primer-Coated Steels

Pulse welding variants of the gas metal arc and flux cored arc welding processes were shown to reduce porosity on PCP-coated steels

BY NICK KAPUSTKA AND PAUL BLOMQUIST

Gas metal arc welding of preconstruction primer-coated steel. (Photo courtesy of Fronius USA.)

Preconstruction primers (PCPs), also called weld-through primers, are used extensively in shipbuilding to preserve the steel during the fabrication cycle and to allow welding without primer removal. Primed material provides savings at initial assembly and at blast and paint of subassemblies or unit blocks. Although these savings are real and significant, the cost to the welding trades is often ignored. While PCPs are rated, tested, and qualified as "weldable primers," most shipyards will agree that PCPs can cause welding problems and often result in a higher degree of rework. Compared to welding uncoated steel, PCPs generally require slower travel speed and the contour of welds made on PCP-coated steels are generally less consistent and often do not meet visual inspection requirements. Welds made on PCP-coated steel also tend to have higher porosity levels than welds made on uncoated steel. Many shipyards first apply the primers, and then spend additional time removing them prior to welding due to difficulties encountered during welding.

Investigating Pulse Welding

Gas metal arc welding (GMAW) and flux cored arc welding (FCAW) are often deployed in shipyards for PCP-coated steels. Both processes are typically performed semiautomatically (i.e., the welder controls the gun) using the constant voltage mode. The successful welding of PCP-coated steels generally requires that the detrimental elements in the primer coating be adequately dissipated from the weld zone through one or more of the following mechanisms: 1) burning off of the PCP coating in front of the weld pool; 2) keeping the weld pool molten long enough for adequate outgassing; and/or 3) combination with fluxing or other alloying elements. When welding through primer, it is critical that the dry film thickness of the primer be equal to or less than the manufacturer's recommended thickness.

The benefits of pulse welding during GMAW and FCAW of PCP-coated steels are being demonstrated during a project funded by the National Shipbuilding Research Program (NSRP). This project has demonstrated that pulse welding methods can be used to reduce porosity in fillet welds made with both the GMAW and FCAW processes using semiautomatic and mechanized welding. It has also been demonstrated that significant travel speed increases can be recognized by using pulse welding with mechanized GMAW of PCP-coated steels.

GMAW and FCAW Operation Modes

With the constant voltage mode (GMAW-CV and FCAW-CV), the voltage is relatively constant, and metal is transferred across the arc in the form of very small drops that are formed and detached at the rate of hundreds per second (Ref. 1). These fine drops are axially accelerated across the arc length (Ref. 2). For the GMAW-CV process, spray transfer requires that argon (Ar) /CO_2 shielding gas mixtures contain a minimum of 75 to 80% Ar, as well as welding current above the spray transition level for the shielding gas mixture, wire type, and wire diameter (Refs. 2, 3). With the FCAW-CV process, spray-like transfer is expected with 75% Ar/25% CO_2 shielding gas. In pulse welding (GMAW-P and FCAW-P), a peak voltage and current occur, as often as several hundred times per second, with the aim of detaching a single droplet from the electrode and transferring it across the arc to the weld pool. Each pulse peak is followed by a background period in which the voltage and current are deliberately lowered with the aim of maintaining an arc and allowing the weld pool to cool. The peak current is above the spray transition current, while the background current is below the spray transition current. One of the primary advantages of pulse welding is the ability to achieve droplet transfer at average current levels below the spray transition current.

When welding through primer, it is critical that the dry film thickness of the primer be equal to or less than the manufacturer's recommended thickness.

Equipment manufacturers have other pulse welding variations in which the current and voltage waveforms are altered with the aim of improving the desired outcome of the weld. The American Welding Society (AWS) does not have a standard term for these pulse welding variations, so the term pulse-over-pulse (PP) is used in this article. The trade name and waveform characteristics vary between manufacturers. For example, one manufacturer has a pulse-over-pulse mode in which a number of relatively high energy pulses are alternated with a number of low energy pulses, causing a weld ripple to be formed each time the low energy pulses fire, and resulting in a very unique weld bead profile. Another manufacturer has a pulse-over-pulse mode in which different parameters are used in what would otherwise be the background portion of the cycle.

Cathodic Cleaning during GMAW and FCAW

The GMAW and FCAW processes use direct current electrode positive (DCEP) polarity. With DCEP polarity, the electrons flow from the base metal to the end of the consumable electrode wire. The work function is the energy required to remove an electron from the surface of a base material (Ref. 4). Oxides and other surface impurities on the weld surface tend to have lower work functions than the base metal itself, and will emit electrons more readily than the base metal. As a result, when welding with DCEP polarity, the arc preferentially seeks out and breaks down oxides and surface impurities on the base metal surface (Ref. 5). This is known as cathodic cleaning and is an inherent advantage of the GMAW and FCAW processes.

The results to date from this project indicate that GMA and FCA welds made on PCP-coated steels using pulse and pulse-over-pulse modes have lower porosity levels than welds made using the corresponding process with the conventional constant voltage mode. It is theorized that cathodic cleaning occurs with each process mode but is more effective when welding with the pulse and pulse-over-pulse modes. With the constant voltage mode, a steady stream of fine droplets is continuously being transferred across the arc to the weld pool. It is presumed that contaminants removed by cathodic cleaning quickly cover the fine droplets in the spray arc stream and thus do not escape, but are redeposited in the weld. In contrast, during pulse and pulse-over-pulse welding there is time during the background portion of the cycle where cathodic cleaning can effectively remove contaminants from the weld pool and base metal surfaces.

Semiautomatic GMAW and FCAW of PCP-Coated Steels

Fillet weld break test specimens were produced per the requirements of Section 4.4.1.12 of NAVSEA Technical Publication S9074-AQ-GIB-010/248, *Requirements for Welding and Brazing Procedures and Performance Qualification*, using GMAW and FCAW to evaluate the effects of the following process modes on the fillet weld break test results: constant voltage, pulse, and pulse-over-pulse. Section 4.4.1.12 of NAVSEA Technical Publication 248 is the procedure qualification test for fillet welds on primer-coated steel (Ref. 6). Section 4.4.1.12 requires that fillet welds be produced on both sides of a T-joint made from primer-coated steel (primer must be present on the edge of the web coupon at the faying interface). The first side weld is then removed and the web is bent over the flange to expose the root of the second-side weld. The fracture surface of the second-side weld is then visually examined per the requirements of Section 4.4.1.12.

A shipyard provided DH-36 steel coupons coated with the current generation of approved primer. An ESAB Aristo 500 power source and matching wire feeder was used along with a U-82 controller. ER70S-3 wire, 0.045 in. diameter, was used with the GMAW process along with 90 Ar/10 CO_2 shielding gas. E71T-1 wire, 0.045 in. diameter, was used for the FCAW process along with 75 Ar/25 CO_2 shielding gas. Programs available in the U82 controller were used for each process variation. All welds were produced in the horizontal position by the same welder.

Test Results

None of the fillet weld break test specimens produced with the GMAW process variants failed to meet the requirements of NAVSEA Technical Publication 248. This outcome was expected knowing that the primer on the DH-36 plate was part of a qualified paint and application system. It was expected that specimens produced with each process variant would have differing numbers and sizes of pores. However, there were virtually no differences in the fillet weld break test results between the process variants of GMAW-CV, -P, and –PP.

Photos of the second-side welds produced with the GMAW-CV and GMAW-PP process variants are shown in Fig. 1. The weld made with GMAW-PP has a much cleaner weld surface with significantly fewer silicate islands compared to the weld made with GMAW-CV. This observation was made for all semiautomatic welds made using these process variants.

The ER70S-3 wire used for these welds contains deoxidizing elements such as silicon that improve the quality of the as-deposited weld. When the fluxing action occurs, the typical result is a number of glassy islands of silicates on the weld surface. The cleaner weld appearance and fewer silicate islands on the surface of the second-side weld made with GMAW-PP is likely attributable to enhanced cathodic cleaning, and improved disintegration of the paint in advance of the weld pool.

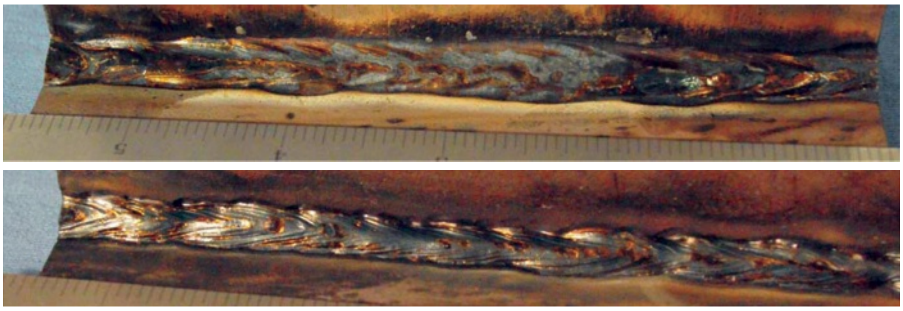

Fig. 1 — Semiautomatic GMAW-CV weld (top) and GMAW-PP weld (bottom) made on the second side of a T-joint specimen produced from PCP-coated DH-36 plate.

The slag layer for the welds made with the FCAW process variants had similar appearance. The fillet weld break test specimens made with each FCAW process variant met the requirements of Section 4.4.1.12 of NAVSEA Technical Publication 248. This is an expected result provided that the primer on the DH-36 plate was part of a qualified paint and application system. However, unlike the GMA welds, the fillet weld break test specimens made with each FCAW process variant had significant differences in the amount and distribution of pores on the fracture surfaces. The fracture surfaces of the second-side weld for T-joints made with each FCAW process variant are shown in Fig. 2. Referring to the top photo, a large number of pores, all less than the ⅟₁₆-in.-diameter limit invoked by NAVSEA Technical Publication 248, are present on the fracture surface of the FCAW-CV weld. Referring to the middle and bottom photos, the fracture surfaces of the FCAW-P and FCAW-PP welds have significantly fewer pores, and the pores that exist are much smaller.

Mechanized GMAW and FCAW of PCP-Coated Steels

Fillet weld break test specimens were produced per Section 4.4.1.12 of NAVSEA Technical Publication 248 using mechanized GMAW and FCAW to evaluate the effects of the process

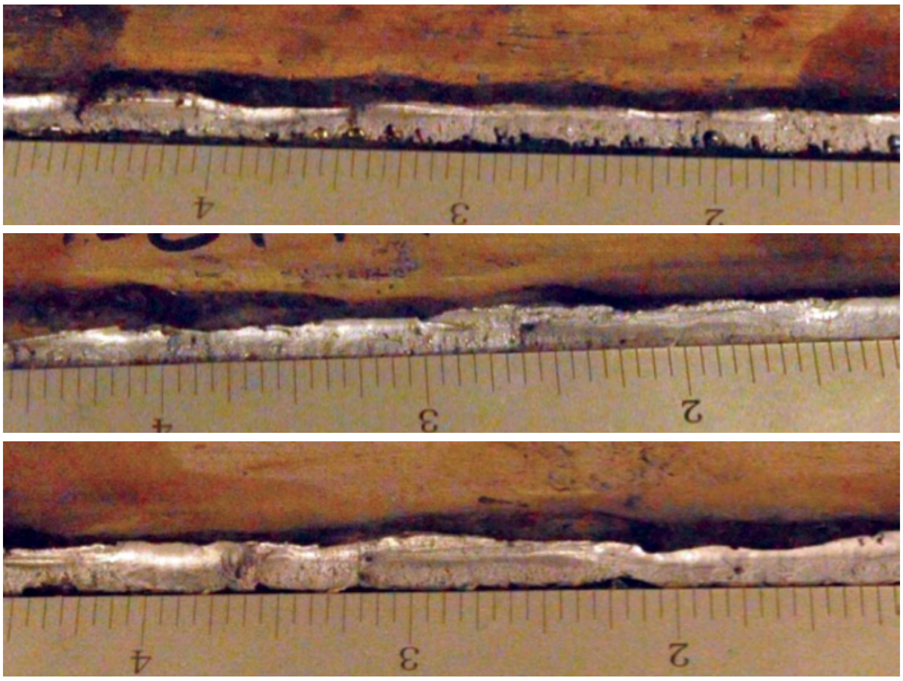

Fig. 2 — Fracture surfaces of semiautomatic FCAW-CV weld (top), FCAW-P weld (middle), and FCAW-PP weld (bottom) made on the second side of a T-joint specimen produced from PCP-coated DH-36 plate.

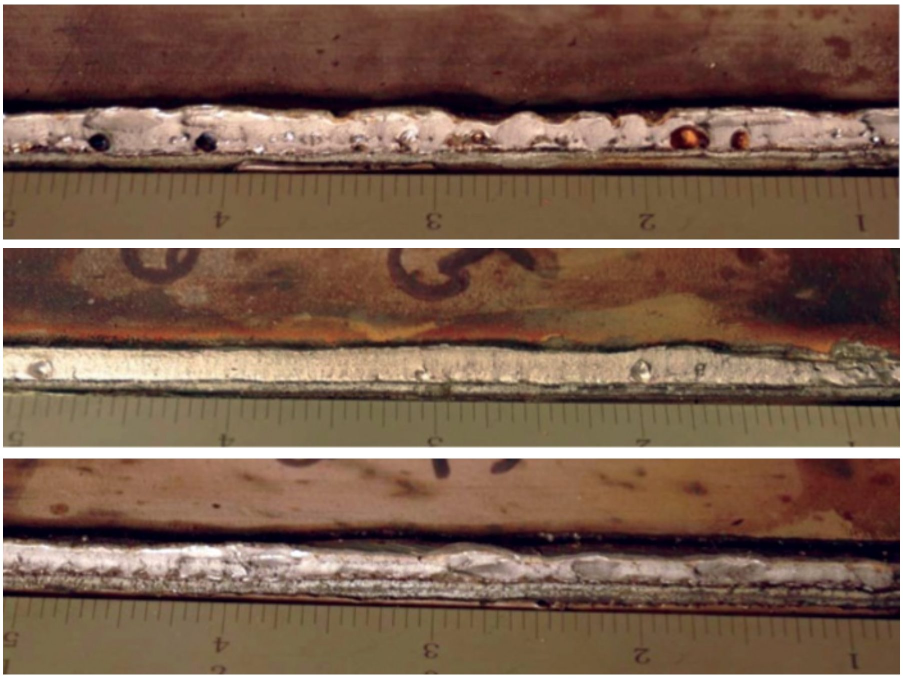

Fig. 3 — Fracture surfaces of mechanized GMAW-CV weld (top), GMAW-P weld (middle), and GMAW-PP weld (bottom) made on the second side of a T-joint specimen produced from PCP-coated DH-36 plate.

variants on the fillet weld break test results. A shipyard provided DH-36 steel coupons coated with the current generation of approved primer. These coupons did not have primer on the edges, so zinc was painted onto the faying interface of the web for the fillet weld break test specimens. ER70S-3 wire, 0.045 in. diameter, was used with the GMAW process along with 90 Ar/10 CO_2 shielding gas. E71T-1 wire, 0.045 in. diameter, was used for the FCAW process along with 75 Ar/25 CO_2 shielding gas. Programs available on the welding system controller were used for each process variation, and all welds were made in the horizontal position.

Fillet weld break test specimens were made using a track-based carriage and the GMAW process variants. An ESAB Aristo 500 power source, matching wire feeder, and U82 controller were used for these specimens. The travel speed was set at 40 in./min, which was the maximum travel speed of the tractor. This speed was useful in evaluating the differences between the process variants, but was not fast enough to establish a top end speed for the GMAW-P and GMAW-PP process variants. Visual inspection of the second-side welds made with each process variant indicated the welds made with GMAW-P and GMAW-PP had cleaner surfaces with fewer silicate islands compared to the GMAW-CV welds.

Unlike the semiautomatic welds made with DH-36 on the faying interface, the fillet weld break test specimens made using mechanized welding with coupons with zinc on the faying interface had significantly higher porosity levels for all welds. The increased porosity levels enabled comparison between the GMAW process variants. The fracture surfaces for the fillet weld break test specimens are shown in Fig. 3. The fillet weld made with GMAW-CV has an erratic weld contour, while the fillet welds made with GMAW-P and GMAW-PP had consistent weld contours. This indicates that a travel speed of 40 in./min is too fast for the GMAW-CV process while a travel speed of 40 in./min is below the maximum travel speed achievable with the GMAW-P and GMAW-PP process variants. The fracture surface of the GMAW-CV weld has four large pores that exceed the 1/16-in.-diameter limit of NAVSEA Technical Publication 248. A large number of smaller pores are present as well, and the pores are dirtier in appearance compared to those on the fracture surfaces of GMAW-P and GMAW-PP welds. The fracture surface of the GMAW-P weld has two pores that exceed the 1/16-in.-diameter limit, along with a few smaller pores. The fracture surface of the GMAW-PP weld has only one pore that is of acceptable size, and there are no small pores present.

T-joint specimens were also welded with mechanized GMAW-CV and GMAW-P to determine differences in the maximum travel speed obtainable with each process variant on PCP-coated steel. As shown in Fig. 4, a crawler robot from Robotic Technolo-

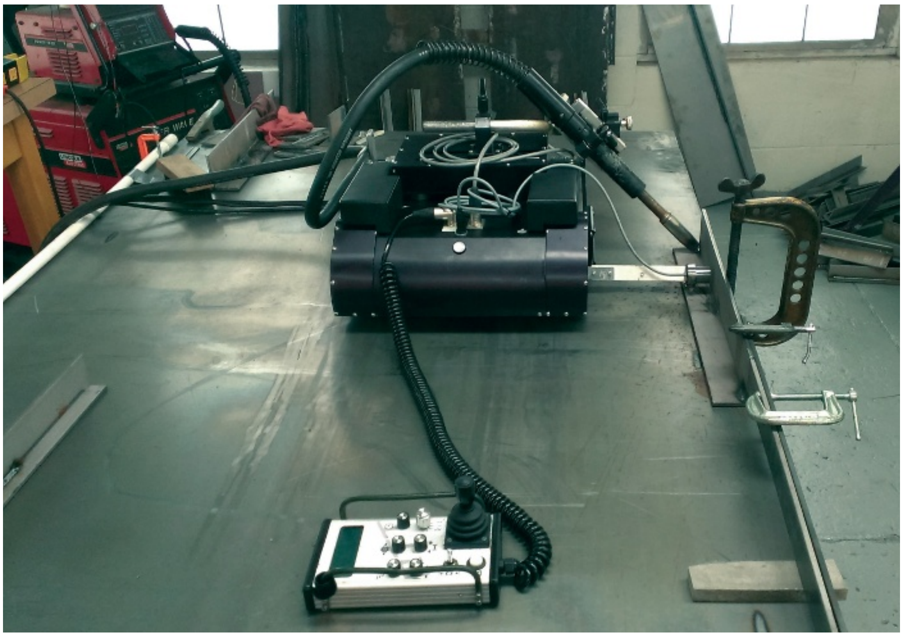

Fig. 4 — RTT crawler robot and Lincoln welding system used to produce T-joints made from PCP-coated DH-36 plate. (Photo courtesy of RTT.)

gies of Tennessee (RTT) was used for these trials along with a Lincoln Power Wave® 455 power source and a matching wire feeder and control unit. Programs available from this welding system were used along with 0.045-in.-diameter ER70S-3 wire and 75 Ar/25 CO_2 shielding gas. Shipyard-provided DH-36 coupons with primer on the top and bottom surfaces were used for these trials. The faying interface did not contain primer and was coated with zinc. Weld quality was evaluated through visual examination. Photos of welds made with each process variant and different travel speeds are shown in Fig. 5. At 40 in./min travel speed the GMAW-CV weld is incoherent. For the GMAW-CV process, it was determined that 36 in./min was the maximum travel speed that could be used to produce a consistent weld profile. Consistent welds were made at 50 in./min travel speed using the GMAW-P process.

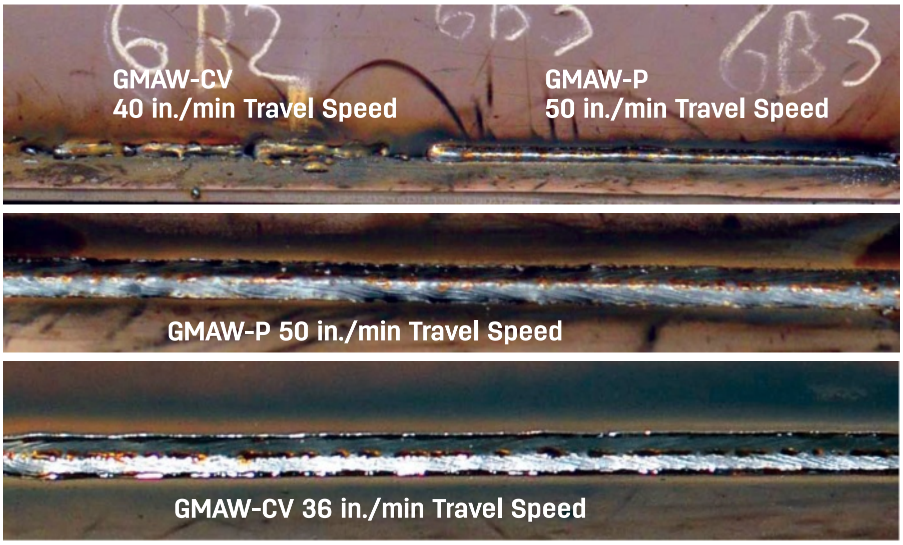

Fig. 5 — T-joint fillet welds made on PCP-coated DH-36 plate using mechanized GMAW-CV and GMAW-P.

Fillet weld break test specimens were made using a track-based carriage and the FCAW process variants. An ESAB Aristo 500 power source, matching wire feeder, and U82 controller were used for these specimens. Mechanized FCAW did not show significant difference between the travel speeds obtainable with the FCAW-CV, FCAW-P, and FCAW-PP process variants. The maximum travel speed obtainable with each process variant was determined to be around 24 in./min. Fillet weld break test results for the mechanized trials were similar to the results from the semiautomatic trials: the fracture surface of the FCAW-CV weld has much higher porosity than the fracture surfaces of the FCAW-P and FCAW-PP welds.

Conclusions

The GMAW and FCAW pulse welding variants that have been studied to date have reduced the porosity content on the fracture surfaces of fillet weld break test specimens made on PCP-coated steels. The GMAW-P process has been shown to increase travel speed by up to 38% during mechanized welding of T-joints, compared to welds made with GMAW-CV. The use of pulse welding did not increase the attainable travel speed for mechanized FCAW of T-joints. An NSRP project team led by EWI is currently demonstrating that the results of this study can be extended to other equipment manufacturers. The project team will also be demonstrating the benefits of pulse welding for PCP-coated steels in several shipyards. WJ

Acknowledgments

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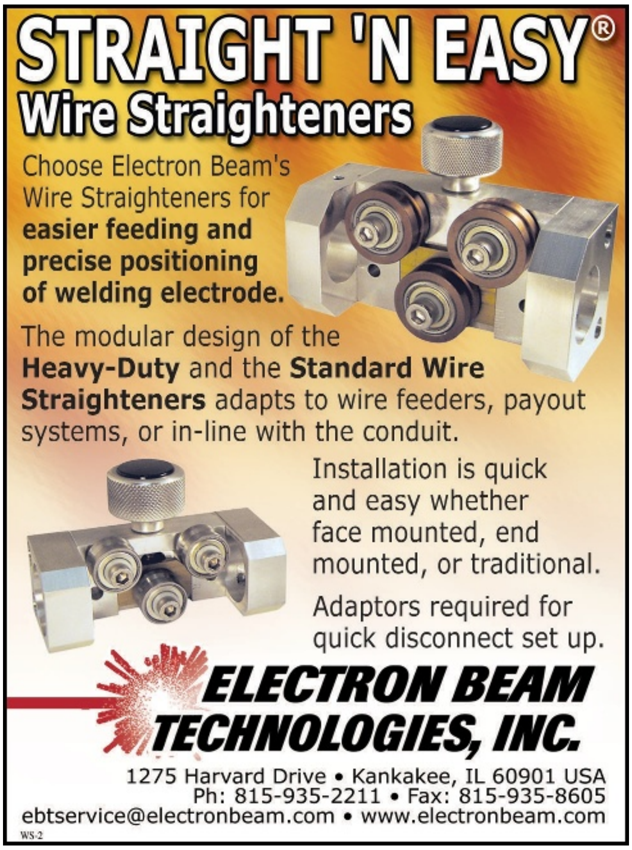

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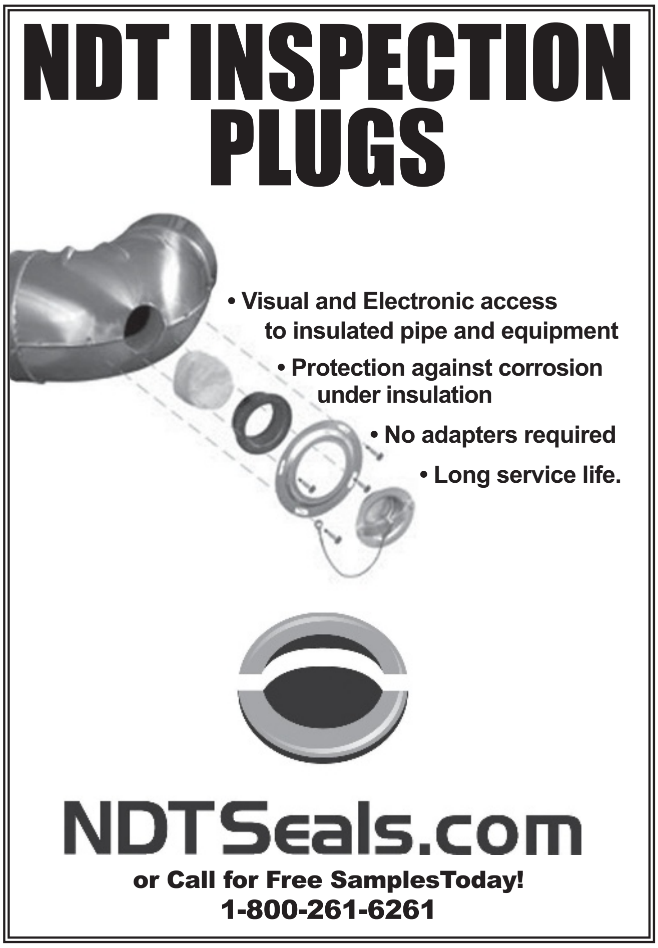

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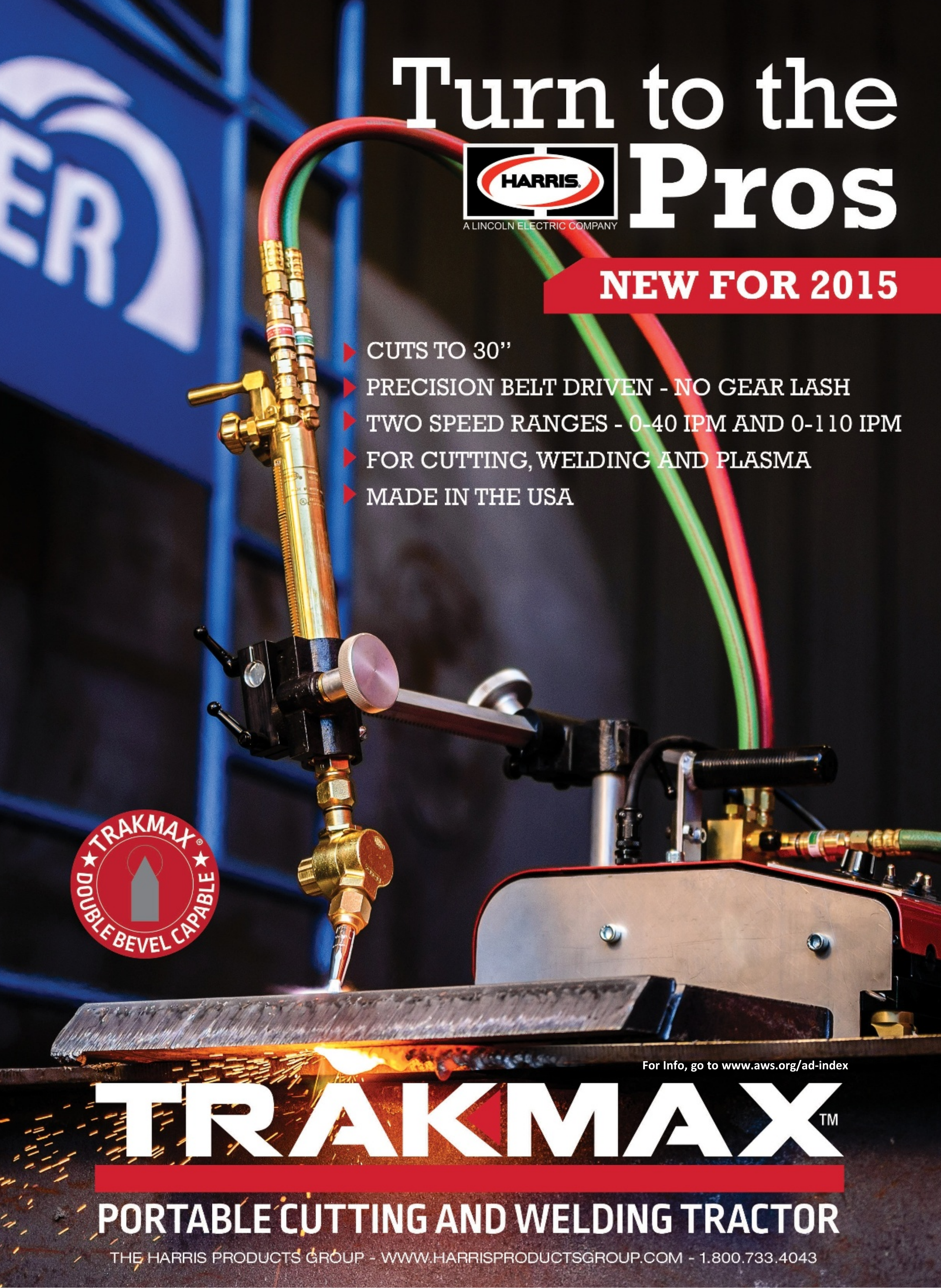

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Note: The 2015 schedule for all certifications is posted online at *www.aws.org/w/a/registrations/prices_schedules.html.*

Certified Welding Inspector (CWI)

Location	Seminar Dates	Exam Date
Birmingham, AL	May 31–June 5	June 6
Hutchinson, KS	May 31–June 5	June 6
Spokane, WA	May 31–June 5	June 6
Pittsburgh, PA	June 7–12	June 13
Beaumont, TX	June 14–19	June 20
Hartford, CT	June 14–19	June 20
Orlando, FL	June 14–19	June 20
Memphis, TN	June 14–19	June 20
Miami, FL	Exam only	June 25
Corpus Christi, TX	Exam only	June 27
Miami, FL	Exam only	July 16
Cleveland, OH	July 12–17	July 18
Jacksonville, FL	July 12–17	July 18
Kansas City, MO	July 12–17	July 18
Los Angeles, CA	July 12–17	July 18
Louisville, KY	July 12–17	July 18
Omaha, NE	July 12–17	July 18
Denver, CO	July 19–24	July 25
Scottsdale, AZ	July 19–24	July 25
Waco, TX	July 19–24	July 25
Bakersfield, CA	July 21–26	July 27
Miami, FL	July 26–31	Aug. 1
Milwaukee, WI	July 26–31	Aug. 1
Sacramento, CA	July 26–31	Aug. 1
Corpus Christi, TX	Exam only	Aug. 1
Baton Rouge, LA	Aug. 2–7	Aug. 8
Chicago, IL	Aug. 2–7	Aug. 8
Las Vegas, NV	Aug. 2–7	Aug. 8
Philadelphia, PA	Aug. 2–7	Aug. 8
Seattle, WA	Aug. 2–7	Aug. 8
Rochester, NY	Exam only	Aug. 8
Mobile, AL	Aug. 9–14	Aug. 15
Portland, ME	Aug. 9–14	Aug. 15
Charlotte, NC	Aug. 9–14	Aug. 15
San Diego, CA	Aug. 16–21	Aug. 22
Minneapolis, MN	Aug. 16–21	Aug. 22
San Antonio, TX	Aug. 16–21	Aug. 22
Salt Lake City, UT	Aug. 16–21	Aug. 22
Alaska, AK	Exam only	Sept. 19
Miami, FL	Sept. 13–18	Sept. 19
Idaho Falls, ID	Sept. 13–18	Sept. 19
St. Louis, MO	Sept. 13–18	Sept. 19
Houston, TX	Sept. 13–18	Sept. 19

9-Year Recertification Seminar for CWI/SCWI

For current CWIs and SCWIs needing to meet education requirements without taking the exam. The exam can be taken at any site listed under Certified Welding Inspector.

Location	Seminar Dates
Pittsburgh, PA	May 31–June 5
Kansas City, MO	June 7–12
San Diego, CA	July 19–24
Miami, FL	July 26–31
Orlando, FL	Aug. 16–21
Denver, CO	Sept. 13–18

Certified Welding Educator (CWE)

Seminar and exam are given at all sites listed under Certified Welding Inspector. Seminar attendees will not attend the Code Clinic portion of the seminar (usually the first two days).

Certified Welding Sales Representative (CWSR)

CWSR exams will be given at CWI exam sites.

Certified Welding Supervisor (CWS)

CWS exams are also given at all CWI exam sites.

Location	Seminar Dates	Exam Date
Minneapolis, MN	July 13–17	July 18

Certified Radiographic Interpreter (CRI)

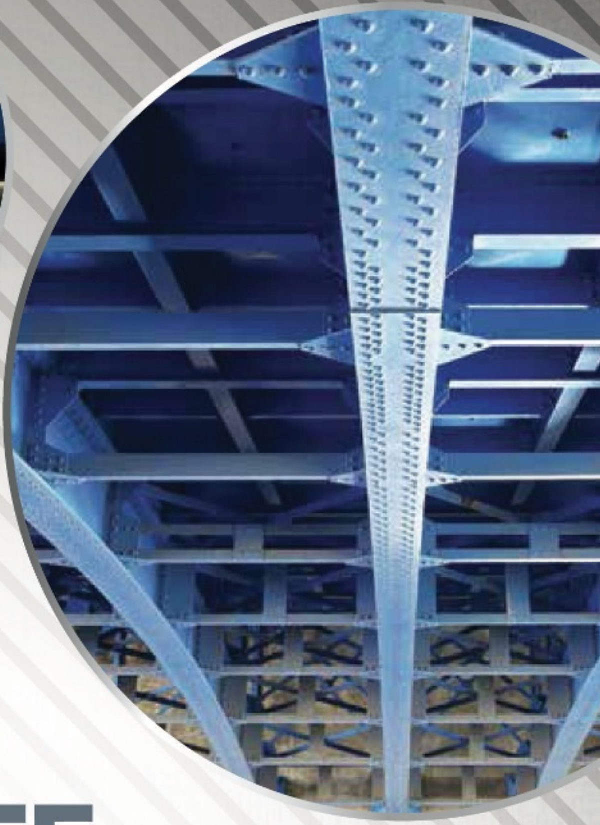
The CRI certification can be a stand-alone credential or can exempt you from your next 9-Year Recertification.

Location	Seminar Dates	Exam Date
Cleveland, OH	June 8–12	June 13
Dallas, TX	Aug. 17–21	Aug. 22
Chicago, IL	Sept. 28–Oct. 3	Oct. 4

Certified Robotic Arc Welding (CRAW)

ABB, Inc., Auburn Hills, MI; (248) 391–8421
OTC Daihen, Inc., Tipp City, OH; (937) 667-0800, ext. 218
Lincoln Electric Co., Cleveland, OH; (216) 383-8542
Genesis-Systems Group, Davenport, IA; (563) 445-5688
Wolf Robotics, Fort Collins, CO; (970) 225-7736
On request at MATC, Milwaukee, WI; (414) 456-5454

IMPORTANT: This schedule is subject to change. Please verify your event dates with the Certification Dept. to confirm your course status before making travel plans. Applications are to be received at least six weeks prior to the seminar/exam or exam. Applications received after that time will be assessed a $250 Fast Track fee. Please verify application deadline dates by visiting our website *www.aws.org/certification/docs/schedules.html*. For information on AWS seminars and certification programs, or to register online, visit *www.aws.org/certification* or call (800/305) 443-9353, ext. 273, for Certification; or ext. 455 for Seminars.



METAL MAKES LIFE MORE: *connected*

As an industry, we make cool stuff. We provide safety, convenience, comfort, energy and much more. The products you make improve daily life—and once a year you have full access to the people, processes and solutions you need to make it all possible.

FABTECH is all about metal. Experience action-packed exhibits, top-notch education and invaluable networking. Ask questions, get answers and find new uses, techniques and trends to drive you to unparalleled levels of productivity. Find details and register at **fabtechexpo.com.**

FABTECH
AWS WELDING CCAI FMA SME PMA METALFORM

AWS FMA sme PMA cai

NORTH AMERICA'S LARGEST METAL FORMING, FABRICATING, WELDING AND FINISHING EVENT

form knowledge **fabricate** solutions **weld** relationships **finish** strong

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fabtechexpo.com

AWS American Welding Society

Friends and Colleagues:

The American Welding Society, in 1990, established the honor of Fellow of the Society to recognize members for distinguished contributions to the field of welding science and technology, and for promoting and sustaining the professional stature of the field. Election as a Fellow of the Society is based on outstanding accomplishment and technical impact of the individual. Such accomplishments will have advance the science, technology and application of welding, as evidenced by:

- Sustained service and performance in the advancement of welding science and technology
- Publication of papers, articles and books which enhance knowledge of welding
- Innovative development of welding technology
- Society and Section contributions
- Professional recognitions

I want to encourage you to submit nomination packages for those individuals whom you feel have a history of accomplishments and contributions to our profession consistent with the standards set by the existing *Fellows.* In particular, I would make a special request that you look to the most senior members of your Section or District in considering members for nomination. In many cases, the colleagues and peers of these individuals who are the most familiar with their contributions, and who would normally nominate the candidate, are no long with us. I want to be sure that we take the extra effort required to make sure that those truly worthy are not overlooked because no obvious individual was available to start the nomination process.

For specifics on the nomination requirements, please contact Chelsea Lewis at clewis@aws.org at AWS headquarters in Miami, or simply follow the instructions on the Fellow nomination form located at http://www.aws.org/awards/fellow_counselor.html. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is August 1, 2015. The Fellows Committee looks forward to receiving numerous Fellow nominations for 2016 consideration.

Sincerely,

Dr. John Elmer
Chair, AWS Fellows Committee

AWS American Welding Society

Friends and Colleagues:

The American Welding Society established the honor of Counselor to recognize individual members for a career of distinguished organizational leadership that has enhanced the image and impact of the welding industry. Election as a Counsel shall be based on an individual's career of outstanding accomplishment.

To be eligible for appointment, an individual shall have demonstrated his or her leadership in the welding industry by one or more of the following:

- Leadership of or within an organization that has made a substantial contribution to the welding industry. The individual's organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities.

- Leadership of or within an organization that has made a substantial contribution to training and vocational education in the welding industry. The individual's organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities.

For specifics on the nomination requirements, please contact Chelsea Lewis at clewis@aws.org at AWS headquarters in Miami, or simply follow the instructions on the Counselor nomination form located at http://www.aws.org/awards/fellow_counselor.html. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is July 1, 2015. The Counselors Committee looks forward to receiving numerous Counselor nominations for 2016 consideration.

Sincerely,

Lee Kvidahl
Chair, Counselor Selection Committee

American Welding Society®
LEARNING
awo.aws.org

CONVENIENT, FLEXIBLE AND ACCESSIBLE

The AWS Online Educational Library is a perfect fit for Welding Students and Instructors

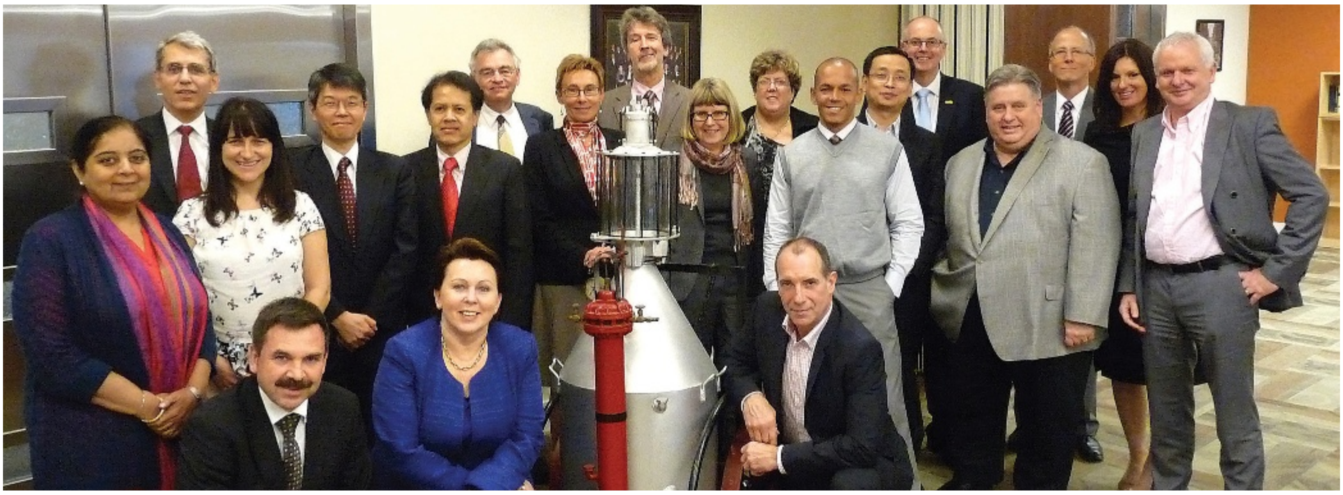
The new AWS Online Educational Library is designed to fit the needs of today's welding students and instructors. Built by AWS subject matter experts and learning professionals, the ever-increasing number of AWS online courses feature engaging multimedia content that stimulates learning and long-term retention. Brief modules, learner-centered navigation, and 24/7 access allow time-strapped students to learn at their own pace from laptops, phones, and tablets at any time and from anywhere. Equally busy instructors can use the AWS learning management system to assign tasks and track student progress.

AWS ONLINE EDUCATIONAL LIBRARY COURSES FEATURE:

- Short modules allow students to digest information in manageable chunks, and allow instructors more flexibility in the assignment of material.
- Learning objectives and module pre-quizzes provide guideposts that students can use to orient themselves and assess their readiness to move on and tackle new material.
- Interactive elements at key junctures throughout each module provide students with ample opportunity to master concepts and formulas.
- Audio narration, animated graphics, and video footage make even the most complex topics both engaging and easy to understand.
- Pause, advance, and rewind navigation features allow students to skip or review course content as needed, giving the student complete control over their learning experience.
- Module quizzes allow students to measure content retention and comprehension.
- AWS learning management system allows instructors to assign tasks, view tests and quizzes, track progress and communicate with students.
- Welding education professionals are available to answer questions through optional weekly office hours.
- Successful students receive an AWS Certificate of Completion that attests to their level of competency.
- AWS online courses qualify as professional development hours that can be used to fulfill AWS recertification requirements.

Learn More and Sign-Up today at *awo.aws.org*

AWS Hosts ISO Conference and Training Sessions



The ISO Technical Management Board members met Feb. 23 and 24 at AWS World Headquarters in Miami, Fla.

The International Organization for Standardization (ISO), a developer and publisher of international standards based in Geneva, Switzerland, convened its Committee Chairs and Convenors Conference, the Americas, for 86 attendees, at AWS World Headquarters in Miami, Fla., Feb. 25 with training sessions conducted on Feb. 26 and 27.

Joseph Tretler Jr., ANSI's VP international policy, and Elisabeth Stampfl-Blaha, ISO VP technical management and chair, ISO Technical Management Board (TMB), gave the opening talks. The TMB members included Claudio Guerreiro (Brazil), Alain Costes (France), Steven Cornish (ANSI, U.S.A.), Parminder Bajaj (India), Amanda Richardson (UK), Ernst-Peter Ziethen (DIN, Germany), Ridzwan Kasim (Malaysia), Yasukazu Fukuda (Japan), Pim Bijl (The Netherlands), Adrian O'Connell (Australia), Heleen Temple (South Africa), Chenguang Guo (China), Susanna Vahtila (Finland), Lars-Gunnar Lundh (Sweden), and Urs Fischer (Switzerland).

The ISO representatives included Kevin McKinley, deputy secretary-general; Sandy Gros-Louis, program manager, technical policy; and Sophie Clivio, TMB secretary.

Houston Team a Finalist in Tough Crew Contest

Welding Engineer David King and his team proved they "Outwork Them All®" to earn a place as one of 12 finalists in this year's Cintas & Carhartt Tough Crew Contest. The competition recognizes crews who work together in all types of climates and in various occupations.

King, an AWS member since 1998, Houston Section, supervises the rig welders at National Oilwell Varco in Houston, Tex.

The winning crew, to be announced shortly, will be outfitted with $2500 in Carhartt® work clothing

The Houston Tough Crew members from left are (front row) Joey Singleton, Luis E. Magallanes, Hiep T. Nguyen, Cesar Barrera, Carlos A. Salazar, and Alfonso R. Molina. Standing are Miguel Vargas, Marco Herrera, Rolando Contreras, Ricardo Canales, Vincent Anzaldua, Abraham Garcia, Miguel Garcia, Trevon Geigley, John Baker, Spencer G. Finkbeiner, Richard Thompson, and David King.

TECH TOPICS

Erratum
D15.1/D15.1M:2012-AMD1
Railroad Welding Specification for Cars and Locomotives

The following erratum has been identified and will be incorporated into the next reprinting of this document.

Page 152, Table 17.2: delete table footnote d.

ISO Draft Standards for Public Review

ISO/DIS 9013, *Thermal cutting — Classification of thermal cuts — Geometrical product specification and quality tolerances*

ISO/DIS 10656, *Resistance welding equipment — Transformers — Integrated transformers for welding guns*

ISO/DIS 18276, *Welding consumables — Tubular cored electrodes for gas-shielded and non-gas-shielded metal arc welding of high-strength steels — Classification*

Copies of these draft standards are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43rd St., 4th Fl., New York, NY, 10036; (212) 642-4900. In the United States, if you wish to participate in the development of International Standards for welding, contact A. Davis, *adavis@aws.org,* ext. 466.

Standard for Public Review

A5.35/A5.35M:201X, *Specification for Covered Electrodes for Underwater Wet Shielded Metal Arc Welding*. 5/4/2015. $25. E. Abrams, *eabrams@aws.org*, ext. 307.

AWS was approved as an accredited standards-preparing organization by the American National Standards Institute (ANSI) in 1979. AWS rules, as approved by ANSI, require that all standards be open to public review for comment during the approval process. The above revised standard is out for public review until the expiration date shown. A draft copy may be obtained from the staff member listed.

Technical Committee Meetings

May 6, 7. A2 Committee and Subcommittees on Definitions and Symbols. Columbus, Ohio. S. Borrero, *sborrero@aws.org*, ext. 334.

May 11. C1 Committee on Resistance Welding, and J1 Committee and Subcommittees on Resistance Welding Equipment. Livonia, Mich. E. Abrams, *eabrams@aws.org*, ext. 307.

May 12. D8 Committee and Subcommittees on Automotive Welding. Livonia, Mich. E. Abrams, *eabrams@aws.org*, ext. 307.

May 18–21. D17 Committee and Subcommittees on Welding in the Aircraft and Aerospace Industries. A. Naumann, *anaumann@aws.org*, ext. 313.

June 4. D16 Committee on Robotic and Automatic Welding. Milwaukee, Wis. P. Portela, *pportela@aws.org*, ext. 311.

Opportunities to Contribute to AWS Technical Committees

The following committees welcome new members. Some committees are recruiting members with specific interests in regard to the committee's scope, as marked below: Producers (P); General Interest (G); Educators (E); Consultants (C); and Users (U). For more information, contact the staff member listed or visit *www.aws.org/w/a/technical/comm_stand.html*.

E. Abrams, *eabrams@aws.org,* ext. 307

Methods of weld inspection, B1 Committee (E, U). **Automotive**, D8 Committee (C, E, G, U). **Cranes, presses, and industrial mill rolls**, D14E and H Subcommittees (C, E, G, U). **Resistance welding**, C1 Committee (C, E, G, U). **Resistance welding equipment**, J1 Committee (E, G, U).

A. Naumann, *anaumann@aws.org*, ext. 313

Oxyfuel gas welding and cutting, C4 Committee (C, E, G, U). **Friction welding**, C6 Committee. **Welding practices and procedures for austenitic steels**, D10C Subcommittee. **Aluminum piping**, D10H Subcommittee. **Chromium molybdenum steel piping**, D10I Subcommittee. **Welding of titanium piping**, D10K Subcommittee. **Purging and root pass welding**, D10S Subcommittee. **Low-carbon steel pipe**, D10T Subcommittee. **Orbital pipe welding**, D10U Subcommittee. **Duplex pipe welding**, D10Y Subcommittee. **Reactive alloys**, G2D Subcommittee (G). **Titanium and zirconium filler metals**, A5K Subcommittee.

P. Portela, ext. 311, *pportela@aws.org*

High-energy beam welding and cutting, C7 Committee. **Robotic and automatic welding**, D16 Committee (C, E, G). **Hybrid welding**, C7D Subcommittee (G).

J. Rosario, ext. 308, *jrosario@aws.org*

Procedure and performance qualification, B2 Committee (E). **Thermal spraying**, C2 Committee (C, E, G, U). **Welding iron castings**, D11 Committee (C, E, G, P, U). **Railroad welding**, D15 Committee (E, G).

J. Molin, ext. 304, *jmolin@aws.org*

Welding sheet metal, D9 Committee (G, P).

S. Hedrick, ext. 305, *steveh@aws.org*

Joining of plastics and composites, G1 Committee. **Safety and Health** Committee (E, U, G, C). **Mechanical testing of welds**, B4 Committee.

R. Gupta, ext. 301, *gupta@aws.org*

Magnesium alloy filler metals, A5L Subcommittee.

MEMBERSHIP ACTIVITIES — New AWS Supporters

Sustaining Members

Bowen Engineering Corp.
8802 N. Meridian St.
Indianapolis, IN 46260
Representative: Andrew G. McKerron
www.bowenengineering.com

Bowen is a self-performing general contractor with a nationwide presence and 45 years' experience. Its primary markets are water, wastewater, energy, industrial, and performance contracting, including site, civil, structural, boilermaker, and mechanical construction.

FEIN Power Tools, Inc.
1000 Omega Dr., Ste. # 1180
Pittsburgh, PA 15205
Representative: Tracy Nedzesky
www.feinus.com/en_us

Founded in 1867 in Germany, FEIN invented the first power tool, an electric hand drill, in 1895. Currently, it produces premium-quality power tools and application solutions for the professional metalworking, interior construction, and automotive sectors.

Industrial Access, Inc.
1155 McFarland 400 Dr.
Alpharetta, GA 30004
Representative: Karen Masters
www.industrialaccess.com

Inox Qatar Co. WLL
PO Box 1217, Doha 11222, Qatar
Representative: Asok Fagunan

Novacero S.A.
Calle J S60-87 Y Calle 3RA
Quito, Pichincha 170126, Ecuador
Representative: Mauricio Franco
www.novacero.com

Otto Arc Systems, Inc.
3921 Sandstone Dr.
El Dorado Hills, CA 95762
Representative: Alan Avis
www.ottoarc.com

Phoenix Products, Inc.
106 Bethford Rd., McKee, KY 40447
Representative: Ronnie Grose
www.acstuff.com

Affiliate Companies

Aberdeen Custom Gate & Iron
PO Box 1733, Weatherford, TX 76086
Applied Materials
3850 Hwy. 2 E., Kalispell, MT 59901

Hi-Tech Weld Overlay Group, LLC
1695 SE Decker St.
Lees Summit, MO 64081

James F. Stearns Co., LLP
42 Winter St., Unit 35
Pembroke, MA 02359

Kadet Products, Inc.
2403 S. J St., Elwood, IN 46036

Laser Dynamics, Inc.
4881 Allen Park Dr.
Allendale, MI 49401

Metalux, Inc.
376 Balm Ct., Wood Dale, IL 60191

Spirit Industries, LLC
3810 Cameron St.
Lafayette, LA 70506

Superweld Co., Inc.
111 Gazza Blvd.
Farmingdale, NY 11735

Virginia Steel Specialties
8444 Old Richfood Rd.
Mechanicsville, VA 23116

Supporting Companies

G. E. Schmidt, Inc.
11236 Williamson Rd.
Cincinnati, OH 45241

Ironform (Imperial Group & DTMP)
311 W. Superior St.
Chicago, IL 60654

Safe Arc Technology, LLC
6873 Johnston St., Ste. B
Lafayette, LA 70503

Welding Distributor

Pacific Consolidated Industries
12201 Magnolia Ave.
Riverside, CA 92503

Educational Institutions

Bullard ISD
1426 S. Houston St.
Bullard, TX 75757

Central Louisiana Technical C. C.
4311 S. MacArthur Dr.
Alexandria, LA 71302

Leander High School
3301 S. Bagdad Rd.
Leander, TX 78641

Lynch Enterprises, LLC
6000 County Rd. 203 # 28
Durango, CO 81301

Tatum High School
600 Crystal Farms Rd., PO Box 808
Tatum, TX 75691

United Tribes Technical College
3315 University Dr.
Bismarck, ND 58504

Webster High School
7564 Alder St. W., PO Box 9
Webster, WI 54893

Willoughby-Eastlake Career Academy
25 Public Sq., Willoughby, OH 44094

AWS Member Counts

April 1, 2015

Sustaining	605
Supporting	342
Educational	716
Affiliate	589
Welding Distributor	53
Total Corporate	2,305
Individual	60,176
Student + Transitional	10,844
Total Members	**71,020**

MEMBERSHIP ACTIVITIES

Member-Get-A-Member Campaign

Listed here are the members participating in the Member-Get-A-Member Campaign that runs from Jan. 1 to Dec. 31, 2015. Members receive 5 points for each Individual Member and 1 point for every Student Member they recruit. For campaign rules and a prize list, see page 81 of this *Welding Journal*. Standings as of March 20. If you have any questions regarding your member proposer points, please call the AWS Membership Department at (800) 443-9353, ext. 480.

J. Morris, Mobile — 126
M. Poss, Detroit — 115
M. Krupnicki, Rochester — 58
H. Hughes, Mahoning Valley— 37
T. Geisler, Pittsburgh— 36
J. Russell, Fox Valley — 27
B. Hackbarth, Milwaukee — 25
J. King, South Carolina — 25
R .Gilmer, Houston — 21
J. Theberge, Boston — 21
N. Baughman, Stark Central — 20
R. Washenesky, Arrowhead — 20
R. Randall, Detroit — 16
D. Saunders, Lakeshore — 16
M. Stevenson, J.A.K. — 16
M. Cyphert, Northwestern Pa. — 15
S. Lord, Rochester — 15
R. Zabel, Southeast Nebraska — 15
W. Elliott, Houston — 14
S. Slagle, Cleveland — 14
J. Pruitt, Kansas City — 13
D. Galiher, Detroit — 11

Student Chapter Award Presented

Craig Donnell, advisor to the Whitmer Career & Technology Center Student Chapter, Northwest Ohio Section, Dist. 11, selected Brian Simon to receive the Student Chapter Member Award. Simon won the local SkillsUSA welding competition and finished fifth at the regional event. He has maintained a 3.9 grade average in the welding program and served as class president for both junior and senior years.

Nominate Your Candidates for These Welding-Related Awards

The deadline for nominating candidates for the following awards is December 31 prior to the year of the awards' presentations. E-mail Chelsea Lewis at *clewis@aws.org* or call (800/305) 443-9353, ext. 293.

William Irrgang Memorial Award

This award includes a $2500 honorarium to recognize the individual who has done the most over the past five years to advance the science and technology of welding.

International Meritorious Certificate Award

The award recognizes, in the broadest terms, the honoree's significant contributions and service to the international welding community.

National Meritorious Award

The award includes a $2500 honorarium to recognize the recipient's loyalty, good counsel, dedication to AWS affairs, and promotion of cordial relations with industry and other technical organizations.

Honorary Membership Award

This award cites an individual who has eminence in the welding profession or has made outstanding developments in the field of welding arts.

George E. Willis Award

The award is presented to an individual who has promoted the advancement of welding internationally by fostering cooperative participation in technology transfer, standards rationalization, and promotion of industrial goodwill for the Society.

Candidates Sought to Receive the MIT Masubuchi Award

The Prof. Koichi Masubuchi award, with a $5000 honorarium, is presented to one person, 40 or younger, who has made significant contributions to the advancement of materials joining through research and development.

Send a list of your candidate's experience, publications, honors, awards, and at least three letters of recommendation from fellow researchers to Prof. Todd Palmer, *tap103@psu.edu*. This award is sponsored annually by the Massachusetts Institute of Technology, Dept. of Ocean Engineering.

District 1

Thomas Ferri, director
(508) 527-1884
Tom_Ferri@Thermal-Dynamics.com

CONNECTICUT

February 24

Activity: The Section held a special event, open to the public, featuring local welding vendors and distributors. The event was held at Asnuntuck Community College in Enfield, Conn.

GREEN & WHITE MOUNTAINS

February 19

Speakers: Burt Riendeau, Dave Schaffer
Affiliation: Airgas
Topic: Setting the AC balance control for gas tungsten arc welding aluminum
Activity: Dist. 1 Director Tom Ferri presented Kevin McLaughlin his Life Member certificate for 35 years of service to the Society. The program was held in Springfield, Vt.

District 2

Harland W. Thompson, director
(631) 546-2903
harland.w.thompson@us.ul.com

Morris County School of Technology Student Chapter

February 25

Activity: The members of the school's Student Chapter, Herbert Browne, advisor, taught students from other classes how to weld as part of the school's Tech Exchange program. Students paid $5 to receive one hour of personal instruction. They learned how to cut the parts with a plasma cutting machine, then weld the two pieces together to make a heart they could take home. The money funds attendance at the SkillsUSA welding event. Harland Thompson, Dist. 2 director, assisted with the training. The Student Chapter is supported by the New Jersey Section.

***CONNECTICUT** — From left are Secretary Joe McGloin, Rick Munroe, Ray Haley, and Chair Steve Goodrow.*

***GREEN & WHITE MOUNTAINS** — Life Member Kevin McLaughlin (right) is shown with Tom Ferri, Dist. 1 director.*

***GREEN & WHITE MOUNTAINS** — Attendees are shown at the February meeting.*

AMERICAN WELDING SOCIETY
MORRIS COUNTY SCHOOL OF TECHNOLOGY
AMERICAN WELDING SOCIETY
MORRIS COUNTY SCHOOL OF TECHNOLOGY

***Morris County School of Technology Student Chapter** — Members pose with Dist. 2 Director Harland Thompson.*

District 3

Michael Sebergandio, director
(717) 471-2065
drweld13@gmail.com.

READING

February 6

Activity: A planning committee met to discuss the upcoming welding competition, awards banquet, Apex tour, and Aug. 21 golf outing. Attending were Chair Richard Heisey, Sharon Bally, Merilyn McLaughlin, Sasa Randjelovic, David Hibshman, Jim Stewart, and Randy Jacobs. The meeting was held at Ozgood's Grill and Bar in Robesonia, Pa.

YORK-CENTRAL PENNSYLVANIA

February 5

Speaker: James N. Colton II
Affiliation: Pennsylvania College of Technology, welding instructor
Topic: Where the welding jobs are
Activity: The Section hosted its Student Chapter members at the college in York, Pa.

District 4

Stewart A. Harris, director
(919) 824-0520
stewart.harris@altec.com

DISTRICT 4

February 9–13

Activity: President David Landon made an extended tour of the schools and industries in the District. The trip of about 1100 miles included Section activities, historical landmarks, and industry visits. Lynn Showalter, deputy Dist. 4 director, organized the tour, assisted by the Section chairs and members.

SOUTHWEST VIRGINIA

February 11

Speaker: David Landon, AWS president
Affiliation: Vermeer Mfg. Co.
Topic: Establishing a certification center at Virginia Western C. C.
Activity: The Section members and Stewart Harris, Dist. 4 director, joined Landon on a tour of the college and later when he spoke to Floyd County High School Student Chapter members. Participating were Gary Young, trades instructor; Deborah Yancey, dean, School of Business, Technology, and Trades; and Doug Thompson, welding instructor.

February 12

Activity: President David and Kay Landon toured the Central Virginia Community College welding lab to meet Instructors Jewel Newman and Andrew Kirby and the students. The discussion concerned the facility becoming an AWS Accredited Testing Facility (ATF) and welding scholarship opportunities.

TRIANGLE

September 27

Activity: The annual golf outing was held at Lakeshore Golf Course in Durham, N.C., coordinated by Eric Umphreyville. Sponsors included Altec Industries, Dynabrade, Hagemeyer, Hypertherm, Lincoln Electric, Miller Electric, Norton Abrasives, Parker Hannifin, and Victor Technologies.

***TRIANGLE** — Some of the attendees are shown at the annual golf outing.*

***READING** — From left are Chair Richard Heisey, Treasurer Sharon Bally, Merilyn McLaughlin, Sasa Randjelovic, David Hibshman, and Jim Stewart.*

***YORK-CENTRAL PENNSYLVANIA** — Pennsylvania College of Technology Student Chapter members are shown at the February program.*

District 5

Carl Matricardi, director
(770) 356-2107
cmatricardi@aol.com

ATLANTA

March 5

Speaker: Carl Matricardi, Dist. 5 director
Affiliation: Welding Solutions, president
Topic: Welding failure that caused the billboard collapse in Snellville, Ga.
Activity: The program was hosted by Lanier Technical College at its new campus in Winder, Ga. Attending were Welding Instructor Tom Rieger and 27 students who learned from Matricardi the importance of following proper prepping and procedures to ensure good welds.

NORTH CENTRAL FLORIDA

February 9

Speaker: Howard Record, Section vice chair, and welding engineer
Affiliation: Record Tool & Die
Topic: Strip cladding
Activity: Following the talk, the 51 attendees gathered in the shop area for a demonstration of strip cladding. The program was held at the Airgas facility in Ocala, Fla.

SOUTH CAROLINA

February 19

Activity: Kenny Angel, construction manager, led the plant tour of the shops at C. R. Hipp Construction, Inc., in North Charleston, S.C.

***NORTH CENTRAL FLORIDA** — From left are Secretary Bill Myers, presenter Howard Record, and Carl Matricardi, Dist. 5 director.*

***SOUTHWEST VIRGINIA** — Above, from left are Gary Young, Deborah Yancey, Dist. 4 Director Stewart Harris, President Dave Landon, and Kay Landon. Below, shown at Floyd County High School are (from left) Dist. 4 Director Stewart Harris, Chair Bill Rhodes, Cody Quesenberry, Camilo Giorgio, Acadia Freeman, Dylan Goad, Kay Landon, President Landon, Tyler Woods, Savanna Duncan, Darren Reed, Cora Macwoodyard-Vladyka, and Doug Thompson.*

***SOUTHWEST VIRGINIA** — At left, President Dave Landon (left) is shown with Ted Alberts, a past Dist. 4 director. At right, from left are President David Landon, Shaq Ingram, Jewel Newman, Marc Ham, E. Roger Cobb Jr., District 4 Director Stewart Harris, Tyler Vece, and Andrew Kirby.*

SOUTH FLORIDA

February 3
Speaker: Galen White, welding engineer
Affiliation: ITW Hobart
Topic: Welding aluminum alloys
Activity: Following the talk, the attendees visited the welding lab for hands-on demonstrations. The program was held at Robert Morgan Educational Center and Technical College in Miami, Fla.

February 6
Activity: South Florida Section Chair Gilly Burrion and members sponsored and assisted the Red Hearts Sisters to stage a casino-style fund-raising event to benefit the homeless and families in need. The event, held in Boca Raton, Fla., featured a Roaring 20s theme.

February 21
Activity: The South Florida Section meeting was followed by a welding show and torch cutting competition, hosted by Florida Gas and Welding Supply in Hollywood, Fla. Danny Zaffino took first-place honors, with runners-up Richard Dewan and Dominic Digirolami. Judges included Chair Gilly Burrion and Ray Blue from Uniweld.

District 6

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District 7

Uwe Aschemeier, director
(786) 473-9540
uwe@sgsdiving.com

CINCINNATI

March 10
Speaker: Jeff Minter
Affiliation: Ben Hur Construction Co.
Topic: Building the St. Louis Gateway to the West Arch
Activity: The program was held at Diamond Oaks Career Campus in Cincinnati, Ohio, for 36 attendees.

COLUMBUS

February 24
Speaker: Kevin Lyttle, senior scientist
Affiliation: Praxair, Inc.
Topic: Shielding gas mixtures to promote low-hydrogen weld deposits
Activity: Attending were members of local chapters of SWE, ASME, ASM International, NSBE, ASNTT, and AIAA. The event was held at La Scala Restaurant in Dublin, Ohio.

JOHNSTOWN-ALTOONA

February 23
Activity: The Section toured the J & J Truck Bodies and Trailers manufacturing facility, a division of Somerset Welding and Steel, Inc. Presenters included J & J General Manager Dave Spear and Mike Riggs, senior VP at Somerset Welding and Steel. Attending were student members from Penn Highlands and Westmoreland County Community Colleges and the Indiana Career and Technology Center.

PITTSBURGH

February 17
Speaker: Murali Tumuluru, researcher
Affiliation: U.S. Steel Corp.
Topic: Welding advanced high-strength steels for automotive applications
Activity: The talk and discussion were held at Springfield Grille in Mars, Pa.

District 8

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(931) 260-7039
djoshuaburgess@gmail.com

NORTHEAST TENNESSEE

March 10
Activity: The Section visited Oak Ridge National Laboratory to see a demonstration of 3D printing technologies, including electron beam melting, ultrasonic extrusion, laser metal deposition, and large area additive manufacturing of polymers and fiber-reinforced polymers. Discussed was how the 3D printed chassis for the *Shelby Cobra* electric car was made. Jonaaron Jones, a research staff member, conducted the program.

District 9

Michael Skiles, director
(337) 501-0304
michaelskiles@cox.net

ACADIANA

February 18
Speaker: Tony DeMarco
Affiliation: DeMarco Welding Services
Topic: Welding problem solving and safety tips for handling gases.
Activity: The event was held at Gator Cove Restaurant in Lafayette, La.

MOBILE

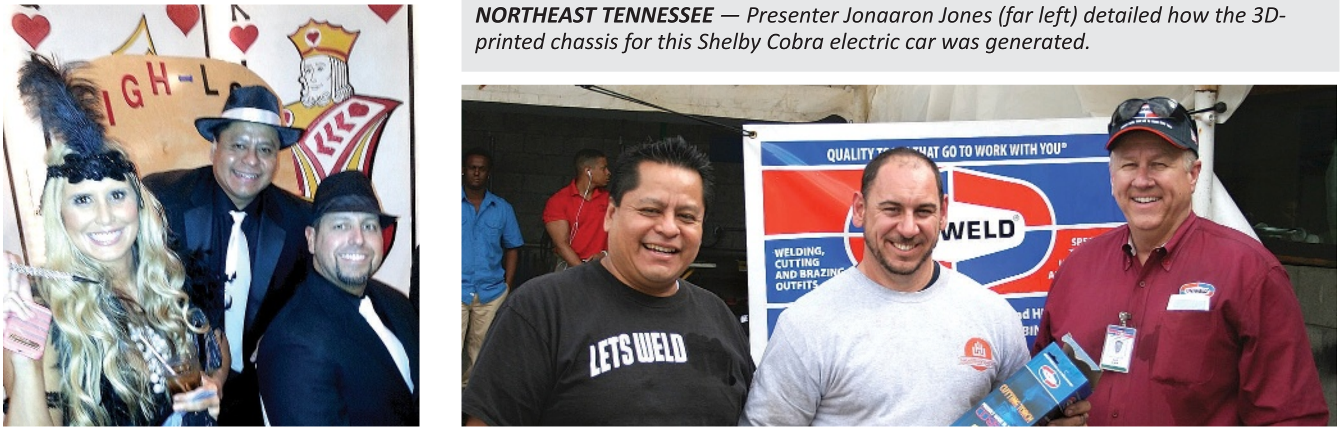
March 12
Speaker: David Landon, AWS president
Affiliation: Vermeer Mfg. Co.
Topic: A Triple Pass of the Torch
Activity: Eleanor Ezell received a plaque commemorating the establishment of a scholarship named in her honor. The event was held at the Original Oyster House in Spanish Fort, Ala.

MOBILE *— From left are Mike Skiles, past AWS President Ron Pierce, honoree Eleanor Ezell, President David Landon, and Chair Michael Zoghby.*

NEW ORLEANS *— D. J. Berger (left) is shown with raffle winner Neal Keller.*

PITTSBURGH — *Speaker Murali Tumuluru (left) is shown with Chair George Kirk.*

NORTHEAST TENNESSEE — *Presenter Jonaaron Jones (far left) detailed how the 3D-printed chassis for this Shelby Cobra electric car was generated.*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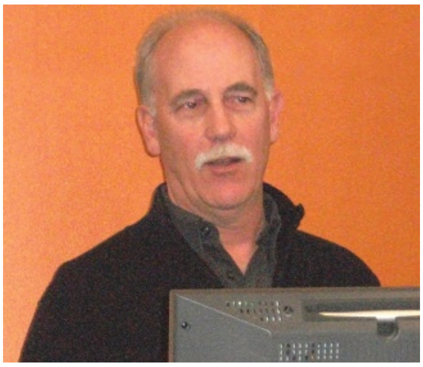
LETS WELD

SOUTH FLORIDA — *At left, proving fund-raising can be fun are Rachael Kinsler, Chair Gilly Burrion (center), and Todd Kinsler. At right are Chair Gilly Burrion, torch-cutting champion Danny Zaffino, and Ray Blue from Uniweld.*



CINCINNATI — *Jeff Minter is shown speaking at the March meeting.*

COLUMBUS — *Speaker Kevin Lyttle (left) is shown with Vice Chair Jim Worman.*

ACADIANA — *Presenter Tony DeMarco.*

JOHNSTOWN-ALTOONA — *Chair Don Howard (left) presents a speaker gift to Dave Spear at J & J Truck Bodies and Trailers.*

NEW ORLEANS

February 24
Speaker: Phil Wickersham
Affiliation: ESAB Welding & Cutting, sales engineer
Topic: Entrepreneur Carl Fisher
Activity: ESAB sponsored this program at Best Western Hotel in Metairie, La. Past Chair Aldo Duron presented Tyler Vial, ESAB territory representative, a sponsor appreciation award. Neal Keller, welding instructor at New Orleans Pipe Trades, won the 50/50 raffle conducted to raise funds for student activities.

District 10

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bobren28@yahoo.com

DRAKE WELL

February 10
Activity: Earl Lytle, VP operations, made a presentation then led the members on a tour of Specialty Fabricating and Powder Coating LLC in Franklin, Pa. The dinner followed at Eat'n Park® Restaurant.

MAHONING VALLEY

March 18
Activity: The Section toured Plumbers and Pipefitters Local 396 in Boardman, Ohio. Marty Loney, training coordinator, conducted the tour and demonstrated pipe welding procedures. Matt Sargent and John Monroe received Section Educator Awards.

NORTHWESTERN PENNSYLVANIA DRAKE WELL

March 12
Activity: The Sections held a joint meeting then toured the farm and distilleries at Sprague Farm Brew Works in Venango, Pa. Brian Sprague conducted the tour.

District 11

Robert P. Wilcox, director
(734) 721-8272
rmwilcox@wowway.com

DETROIT

March 12
Speaker: Scott Viciana, vice president
Affiliation: Ventower Industries
Topic: Wind power in Michigan
Activity: This old timers' night program included members of the Detroit chapter of ASNT. Recognized for 25 years of service to the Society were Edward Warzyniec Jr. and Richard Pietron Jr. who received their Silver Member certificates from John Sutter, the Section's old timers chair. The event was hosted by Ventower Industries LLC in Monroe, Mich.

District 12

Daniel J. Roland, director
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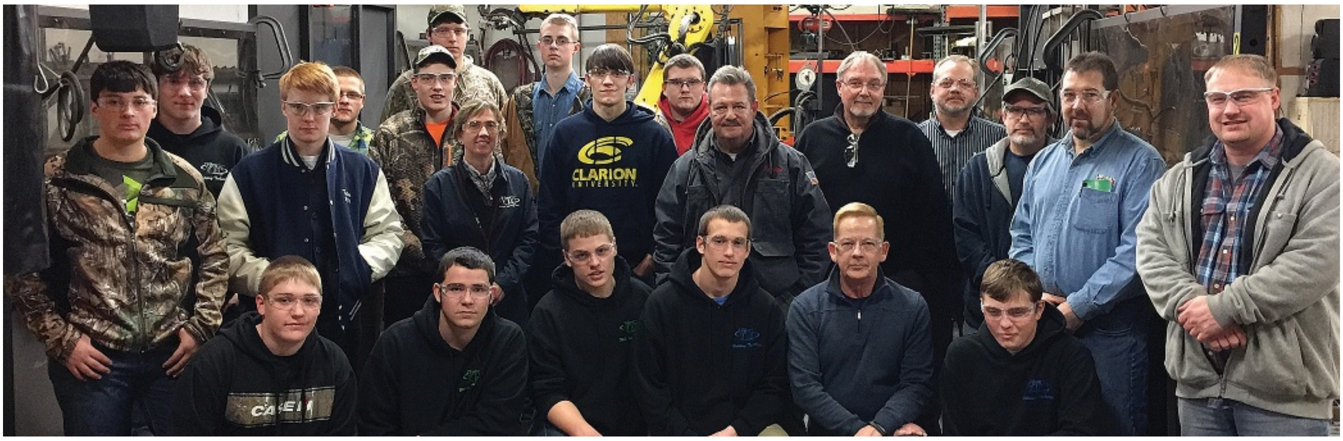
***MILWAUKEE** — From left are Barbra Weiss, Sue Silverstein, Chair Paul Fischer, Bob Bruss, Nate Liszewski, and speaker Stanley Weiss.*

***MAHONING VALLEY** — Training Coordinator Marty Loney led the tour.*



***DRAKE WELL** — Attendees are shown during their tour of Specialty Fabricating and Powder Coating in Franklin, Pa.*

LAKESHORE

February 19

Activity: The Section held its first trivia contest night at CNC Links Golf Course and Restaurant in Manitowoc, Wis. The teams competed to answer questions in five different areas of welding.

MILWAUKEE

February 19

Speaker: Stanley Weiss, professor
Affiliation: University of Wisconsin at Milwaukee, and MIT
Topic: Case studies in failure analysis
Activity: The program was held at Toms Foolery Bar & Grill in Milwaukee, Wis.

RACINE-KENOSHA

March 4

Activity: The Section members and participants in the Gateway Technical College welding program toured The Scharine Group, Inc., in Whitewater, Wis., a supplier of dairy and livestock equipment and industrial racks and dollys.

DETROIT *— John Sutter (left in both photos) is shown with 25-year members Richard Pietron Jr. (left) and Edward Warzyniec Jr.*

NEW ORLEANS *— From left are Aldo Duron, Tyler Vial, and speaker Phil Wickersham.*

MAHONING VALLEY *— At left, Matt Sargent (right) receives the Section Educator Award from Chair Chuck Moore. At right, from left are Treasurer Kenny Jones with Laurel Technical Institute Welding Instructors Brian Bickel, John Monroe, and Delayne Jacobs.*

NORTHWESTERN PENNSYLVANIA *and* ***DRAKE WELL*** *— Members seem to be having a good time at Sprague Farm Brew Works in March.*

District 13

John Willard, director
(815) 954-4838
kustom_bilt@msn.com

CHICAGO

February 12
Activity: The Section held its annual St. Valentine's party at Cooper's Hawk Winery & Restaurant in Burr Ridge, Ill., for 75 attendees.

February 18
Activity: The board members held a planning meeting at Outriggers Flame Restaurant in Countryside, Ill.

District 14

Robert L. Richwine, director
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rlrichwine2@aol.com

INDIANA

February 26
Activity: The Section toured the Midwest Technical Institute welding facility. Lead Welding Instructor Kyle Brown gave a presentation, then he and Instructor Nick Umberger conducted the tour.

LOUISVILLE

February 24
Speaker: Ben Coons, technical sales representative
Affiliation: The Lincoln Electric Co.
Topic: Programmable welding machines
Activity: Following the talk, Coons coached attendees with hands-on demonstrations of several processes. The event was held at Welders Supply Co. in Louisville, Ky.

ST. LOUIS

February 19
Activity: The Section visited Pandjiris®, a manufacturer of weld positioning and welding automation equipment. Owner Bob Mann and Bob Palovcsik conducted the tour.

District 15

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dave@learntoweld.com

District 16

Karl Fogleman, director
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fogleman3@cox.net

NEBRASKA

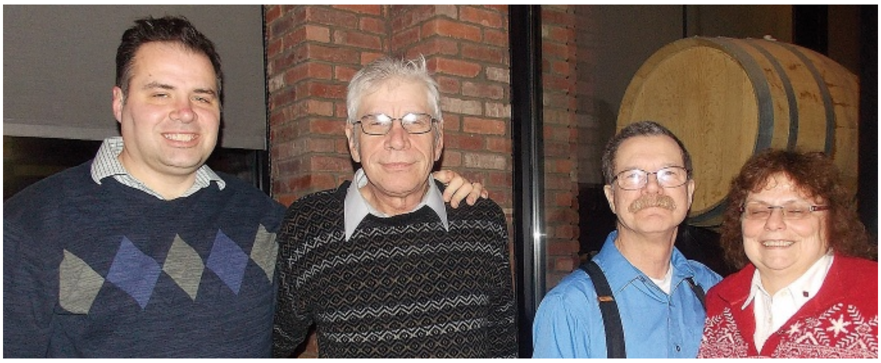
February 19
Activity: The members joined welding students from local schools to tour the Omaha Public Power District North Omaha Station, a coal-fired plant.

RACINE-KENOSHA *— Attendees are shown during their tour of The Scharine Group, Inc.*

ST. LOUIS *— Attendees are shown during their tour of Pandjiris®.*

***INDIANA** — Kyle Brown, lead welding instructor at Midwest Technical Institute, is shown during his presentation.*

***INDIANA** — Welding Instructor Nick Umberger (right) works with student Steve Deckard on a pipe welding assignment.*



***CHICAGO** — Top photo, shown at the St. Valentine's party are from left (standing) Jeff Stanczak, Gary Bernal, Marty and Rita Vondra, Sandie Bernal, and Darius Bunda, (seated) Frank and Patty Perrotta and Kamila Bunda. Center photo shows board members from left (front row) Cliff and Anghelina Iftimie, and Bob Zimny, (middle row) Vicky Darnell, Craig Tichelar, and AWS Past President Jim Greer, (back row) Monty Vondra and Jeff Stanczak. Above are (from left) Steve and Jeff Stanczak and Scott and Linda Brissey.*

***LOUISVILLE** — Attendees are shown at the February program.*

District 17

Jerry Knapp, director
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EAST TEXAS

February 16
Speaker: David Landon, AWS president
Affiliation: Vermeer Mfg. Co.
Topic: A Triple Pass of the Torch
Activity: Attending the event were students from LeTourneau University and Kilgore College Welding Technology Programs.

NORTH TEXAS

March 12
Speaker: Linda Lewis-Roark, owner
Affiliation: Grapevine Foundry
Topic: Investment casting bronze
Activity: Instructor Ron Theiss and his 9-year recertification class members visited the foundry to study bronze casting using the lost-wax process from mold making through pouring the liquid metal.

OKLAHOMA CITY

February 19
Speaker: David Alcorn
Affiliation: American Piping Inspection
Topic: Radiographic NDE
Activity: The program began with a tour of Boardman Co., a steel plate and pressure vessel fabricator.

TULSA

February 22
Activity: The Section members and Jerry Knapp, Dist. 17 director, participated in the Tulsa Welding School welding contest featuring 262 high school contestants. Tulsa School officials included Mark Staats, president; Brian Seitz, welding school dean; and Tom Moffit, NDE instructor. Assisting was Joe Frazier from Metallurgical Services.

District 18

John Stoll, director
(713) 724-2350
John.Stoll@voestalpine.com

HOUSTON

January 21
Speaker: Ross Jones, vice chair
Affiliation: Agricultural Mechanics Contest at the Houston Rodeo
Topic: How the contest is a job fair
Activity: Chair Barney Burkes accepted the Henry C. Neitzel National Membership Award recognizing the Section's achieving the highest percentage increase in membership.

February 18
Speaker: Scott Witkowski, president
Affiliation: Maverick Testing Laboratories, Inc.
Topic: How to prepare for a welding performance test
Activity: This students' night program attracted 440 members, students, and educators.

EAST TEXAS *— At left, from left are Christopher McBride, Jon Spencer, President David Landon, Wes Downing, Ed Peterson, Joshua Shaver, Gabe Johnson, and Ty Helgeson. At right, President Landon is greeted by Chair J. Jones.*

NEBRASKA *— Members and students are shown during their tour of the Omaha Public Power District Station.*

LAKE CHARLES

March 18

Speaker: Curtis Hayes, technical sales representative

Affiliation: The Lincoln Electric Co.

Topic: VRTEX 360® virtual reality arc welding trainer

Activity: The attendees competed for the highest welding score. Drew Fontenot, a welding instructor and Section board member, took first place. The event was held at Logan's Roadhouse Restaurant in Lake Charles, La.

***HOUSTON** — At left, Chair Barney Burkes (left) is shown with speaker Ross Jones. At right, Dist. 18 Director John Stoll (left) presents Chair Barney Burkes the Henry C. Neitzel National Membership Award.*

***OKLAHOMA CITY** — Shown are David Alcorn (left) and Chair Cary Reeves.*

***TULSA** — From left are Mark Staats, Tom Moffit, Joe Frazier, Brian Seitz, and Jerry Knapp, Dist. 17 director.*

***OKLAHOMA CITY** — Attendees are shown at the Boardman Co. tour.*

***NORTH TEXAS** — Linda Lewis-Roark demonstrated investment casting for Ron Theiss (wearing a jacket) and his CWI class members.*

District 19

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kenneth.johnson@vigorindustrial.com

BRITISH COLUMBIA

January 21
Speaker: Chris Norris
Affiliation: Wolf Robotics
Topic: Robotic welding automation
Activity: The program was held at the UA Piping Industry College of British Columbia in Delta, B.C., Canada.

February 26
Speaker: Mahyar Asadi
Affiliation: SKC Engineering
Topic: Welding simulation for the perfect weld
Activity: The event was held at the UA Piping Industry College of British Columbia in Delta, B.C., Canada.

PUGET SOUND OLYMPIC

February 5
Speaker: Omar Simon, owner
Affiliation: Simon Forensic
Topic: Failure analysis techniques
Activity: The event was held at Bellevue Coast Hotel in Bellevue, Wash.

February 13, 14
Activity: Jennifer Bernard and Shawn McDaniel supervised while Art Schnitzer, Steve Pollard, and Robert White assisted in proctoring 62 CWI exams. The activity was held at the DoubleTree in SeaTac, Wash.

SPOKANE

February 18
Speaker: Richard Warrington, artist
Activity: This ladies' night program was held at Luigi's Italian Restaurant in Spokane, Wash.

District 20

Pierrette H. Gorman, director
(505) 284-9644
phgorma@sandia.gov

IDAHO/MONTANA

February 27
Speaker: Pierrette Gorman, Dist. 20 director, laser welding engineer
Affiliation: Sandia National Laboratories
Topic: Special seminar on laser welding
Activity: The event was held at Idaho Falls Activity Center.

District 21

Sam Lindsey, director
(858) 740-1917
slindsey@sandiego.gov

LOS ANGELES/INLAND EMPIRE

February 17
Speaker: George Rolla, chair, CWI, CWE, CW
Affiliation: Advanced Weldtec, Inc.,
Topic: Overview of D1.1, *Structural Welding Code — Steel*, for CWI and Los Angeles city certification
Activity: The event was held at Maggie's Pub in Santa Fe Springs, Calif.

NEVADA

February 26
Speaker: Uwe Aschemeier, Dist. 7 director
Affiliation: Subsea Global Solutions
Topic: Underwater welding
Activity: Following the talk, Aschemeier demonstrated his craft using a large fish tank, then urged each attendee to try underwater welding for the first time.

February 27
Activity: Uwe Aschemeier, Dist. 7 director, visited the USAF Thunderbirds hangar at Nellis AFB in Las Vegas, Nev. Staff Sgt. Francisco Garrigas, nondestructive inspection technician, guided his tour of the facility.

District 22

Kerry E. Shatell, director
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kesi@pge.com

SACRAMENTO VALLEY

November 2
Activity: The Section officers and Sierra College students worked one-on-one with local Boy Scouts in the safe and proper use of SMA and GMA welding to help them earn their welding merit badges. The training was performed at the new Sierra College Mobile Training Unit in Granite Bay, Calif.

February 18
Activity: The Sacramento Valley Section toured the SIEMENS railcar manufacturing plant in Sacramento, Calif. Mayk Lehmann, director of weld quality, led the program.

SAN FRANCISCO

February 4
Speakers: Rick Wittrock, Dan Duman
Affiliation: Brightlight Welding
Topic: A study of an independent fabrication shop
Activity: The program was conducted by Scott Miner, student affairs committee chair, at Ricky's Sports Theatre and Grill in San Leandro, Calif.

***HOUSTON** — Speaker Scott Witkowski (behind the lectern) and educators are shown at the students' night program Feb. 18.*

PUGET SOUND OLYMPIC — Speaker Omar Simon (right) is shown with Ken Johnson, Dist. 19 director.

IDAHO/MONTANA — Pierrette Gorman, Dist. 20 director, led the laser welding seminar.

NEVADA — SSgt. Francisco Garrigas and Uwe Aschemeier, Dist. 7 director, are shown with F-16 jet No. 5. The number is inverted because this plane flies upside-down during the Thunderbirds air show.

SPOKANE — Chair Phil Zammit (left) is shown with artist Richard Warrington.

BRITISH COLUMBIA — From left are Steve Pollard, speaker Chris Norris, Bob Olson, and Ken Johnson, Dist. 19 director.

SAN FRANCISCO — From left are presenters Rick Wittrock and Dan Duman with Scott Miner.

LOS ANGELES/INLAND EMPIRE — Attendees are shown at the February event.

BRITISH COLUMBIA — Speaker Mahyar Asadi (left) and Chair Scott Stanley.

SACRAMENTO VALLEY — Chair Bill Wenzel (white shirt) is shown with presenter Mayk Lehmann (left) and Brandon Beattie (right).

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Railroad Welding, Thermal Spraying, Welding Iron Castings, Welding Qualification

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American Welding Society

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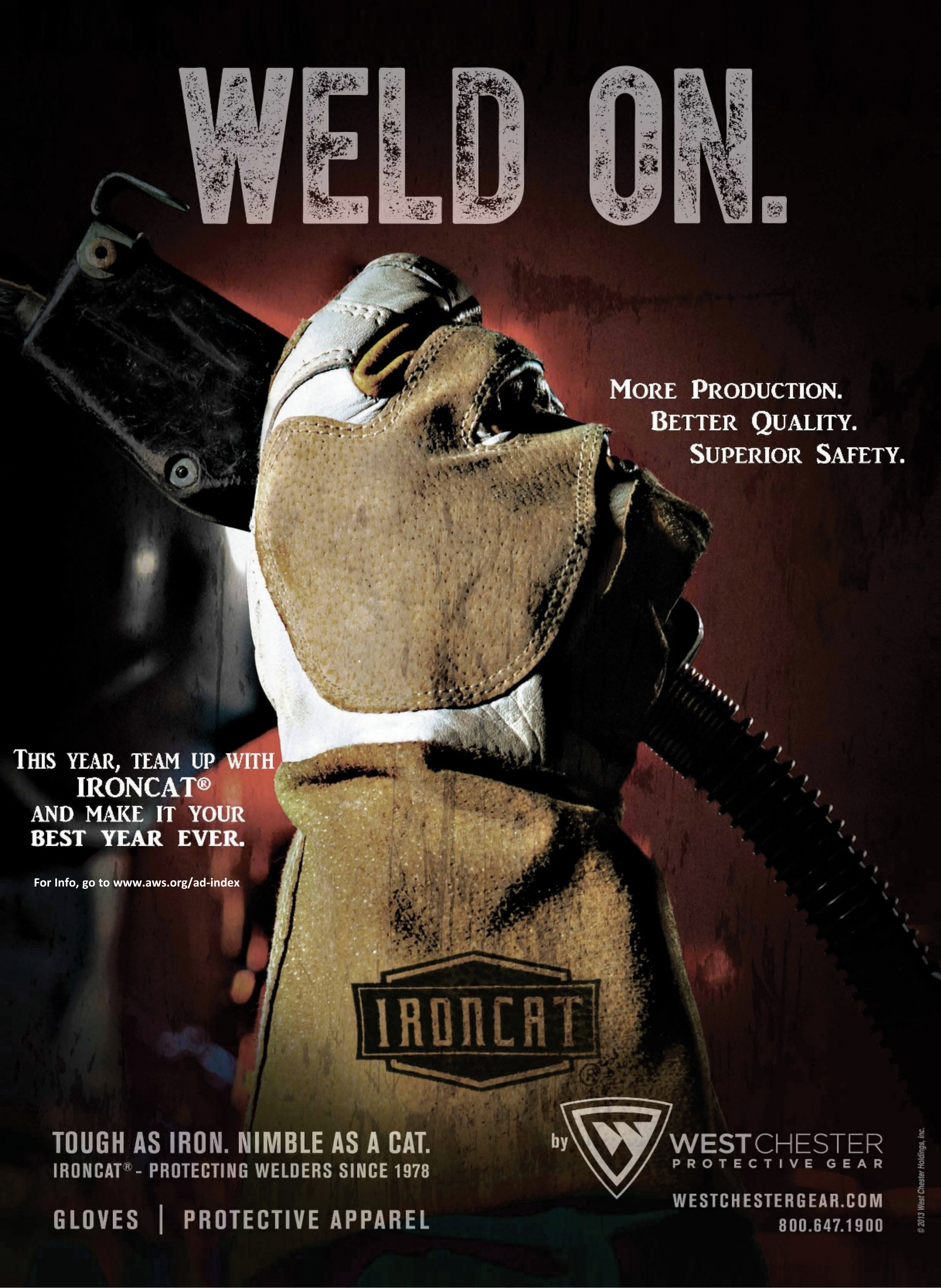

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Walter Surface Technologies Appoints President, COO

M. Christodoulou

Walter Surface Technologies, Montreal, Q.C., Canada, has appointed Michael Christodoulou president and chief operating officer. Previously, Christodoulou worked since 1985 at Cummins Eastern Canada LP, a distributor of diesel engines, where he most recently served as president, Cummins Diesel of Canada.

Hobart Institute Names Career Development Rep

Calvin Scharrer

Hobart Institute of Welding Technology, Troy, Ohio, has named Calvin Scharrer career development representative. Before joining the Institute, Scharrer served as a high school admissions representative at Lincoln College of Technology. In his new post, he will conduct tours, give presentations about the Institute's welding programs to high schools and career center students, and assist graduating students with career placement.

Spectronics Fills Two Key Posts

Spectronics Corp., Westbury, N.Y., a supplier of ultraviolet products and fluorescent materials used for inspections and leak detection, has promoted Daniel Chusid to technical sales and regulatory compliance specialist, and appointed Daniel Tristan international sales manager for the Latin America and Asia-Pacific regions. With the company for eight years, Chusid most recently served as international customer service and technical sales specialist. Before joining the company, Tristan was director of sales and marketing at Dreyfus Global Trade, an export management company serving the automotive, heavy-duty, and industrial markets.

Fronius Adds Tech Support

Seth Perrin

Fronius USA, LLC, Portage, Ind., has hired Seth Perrin as a sales application engineer based in Portage. Perrin gained his interest in welding during his 5-year tour in the U.S. Marine Corp. He holds a degree in welding fabrication and engineering from Pennsylvania College of Technology.

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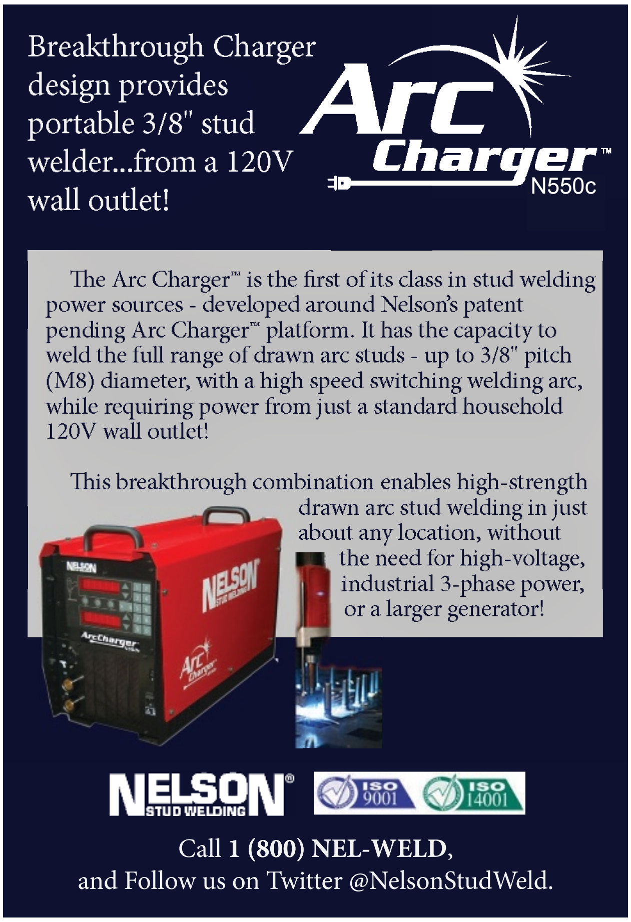

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Quality Industries Builds Its Leadership Team

Quality Industries, Inc., La Vergne, Tenn., a precision metal fabricator, has named Chris Fann senior vice president of operations, and Gary Carter vice president, information technology and enterprise transformation. Fann most recently served as senior vice president at Dura Automotive. Carter, a CPA and certified information systems auditor, previously served as an engagement partner at Vaco, a consulting firm.

Superior Tube Names Sales Manager

Erik Latranyi

Superior Tube, Collegeville, Pa., and UK-based Fine Tubes have appointed Erik Latranyi sales manager — Americas. Latranyi, with 25 years of experience in international sales in the industry, will represent both companies throughout Canada, North, Central, and South America, and Mexico. His markets will include aerospace, oil and gas, nuclear, power-generation, and medical. Previously, he held managerial positions at Structural Group, Kelford Energy, and Hendrick Mfg. Co.

TRUMPF Announces International Staff Changes

Luis Colunga

Stefan Fickenscher

TRUMPF, Farmington, Conn., has appointed Luis Colunga national sales manager in Mexico and Stefan Fickenscher managing director, TRUMPF Canada. Based in Apodaca, Colunga will be responsible for all machine tool division sales throughout the country and supervise activities of Metalforte, the company's machine tool sales representative. He brings more than 20 years of experience in the precision sheet metal fabrication industry gained at several companies in Mexico. Fickenscher previously held positions at TRUMPF in Germany before transferring to Connecticut. He succeeds Stefan Schreiber who returns to TRUMPF GmbH + Co. KG in Ditzingen, Germany, where he serves as head of central sales subsidiaries in the machine tool division.

Wagner Hires Two Sales Managers

Bob Gueldenzopf

Doug Schaefer

The Wagner Companies, Milwaukee, Wis., a manufacturer of handrail fittings and metal products, has hired Bob Gueldenzopf sales manager for architectural systems and Doug Schaefer as sales manager for architectural railing systems. Gueldenzopf has 20 years experience with Ruud Lighting, Phoenix Products, and EYE Lighting. Schaefer has 25 years of experience in lighting design working with Visa Lighting, Kohler Co., SPI Lighting, and Manning Lighting, Inc.

PMA Elects Board Chairmen

The Precision Metalforming Assn. (PMA), Cleveland, Ohio, has elected William R. Smith chairman of its board of directors, Ron Lowry first vice chair, and David Arndt second vice chair and treasurer. Smith is CEO of Termax Corp., Lake Zurich, Ill. Lowry is CEO and owner of Dayton Rogers in Minneapolis, Minn.; and Arndt is president of Pentaflex, Inc., in Springfield, Ohio.

Solar Companies Appoint Canadian Sales Rep

Harry Hall

Solar Atmospheres and Solar Manufacturing, Souderton, Pa., named Harry Hall a sales representative focusing on the vacuum processing markets in Canada. Hall has extensive experience in the heat-treating industry. In 1989, he founded Aberfoyle Metal Treaters, Ltd., in Ontario, Canada, specializing in large-scale heat treating projects for heavy industries.

Konecranes Hires Two Machine Tool Specialists

Konecranes, a manufacturer of lifting equipment, Springfield, Ohio, has added Jim Foust and Tim Ellis to its Machine Tool Service team in Cincinnati, Ohio, as specialists in the Giddings & Lewis machine tool product line. Foust previously served as CNC machine tool applications product manager for VMC Technologies, Inc., for eleven years. Before joining the company, Ellis served Giddings & Lewis for 38 years, where he served as service manager and manager of remanufacturing sales for many years.

AMT Elects Board of Directors

The Association for Manufacturing Technology (AMT), McLean, Va., elected Jerry Rex chairman of the board. He is executive vice president, Concept Machine Tool, Plymouth, Minn. Rex succeeds Kevin J. Kilgallen, who is president of Mid Atlantic Machinery, Harrisburg, Pa. Elected 1st vice chair was Richard L. Simons, chair, president, and CEO of Hardinge, Inc. Second vice chair and treasurer is Ronald S. Karaisz, president and CEO of Kar Enterprises, Inc./Novi Precision Products, Inc. Brian J. Papke, president of Mazak Corp., was elected secretary.

Proper Maintenance Can Prevent Wire Feeding Difficulties

An experienced welder discusses how to avoid common wire feeding problems

BY DAVID LEE

I've had some really good days in my nearly 25 years as a forging tool and die welder. The die is hot enough, the radio is playing loud, and the boss is on vacation. All I have to do is keep the wire (flux cored arc welding (FCAW) in most cases) running at 20 lb/h. Easy, right? Few things can turn a good day into a bad one faster than feeding problems for a welder running wire.

In my experience, the feeder itself is usually not the problem. The problem starts at the drive rolls, and can run all the way to the tip. It starts off as what is described as "chatter" or "stutter" — the wire refuses to feed smoothly and the welder can feel the resistance in the handgun.

Gas metal arc welding (GMAW) guns come in many different sizes and run a variety of diameters and types of wires. From mild steel to aluminum, tool steel to copper based, GMAW machines are in use in many industries. It doesn't matter where they are found, whether in the robotics-rich environment of the automotive plant or in the neighbor's garage, the things they all have in common are the drive rolls, cable, and gun that delivers the filler metal and shielding gas (or not) to the area needing welding.

Whether you are running solid or flux cored wire, shielded or open arc, even submerged arc, wire feeding problems are encountered in all of these types of welding. You've literally run miles of wire through your gun flawlessly, with just regular tip changes, and then it acts up.

Problems and Solutions

Let's look at what I have found to be areas that, when regular maintenance is done, will prevent you from having a good day go bad.

❶**Problem:** Drive rolls not cleaned or adjusted properly. The drive roll groove (and knurls on rolls so configured) can become packed with the drawing compound, used in the manufacture of the wire to reduce the size of nearly all the solid or flux core wire used in the GMAW applications, industrial grit from grinding and smoke from welding. This can affect the tensioning and grip on the wire. Smooth rolls used for solid wire are less affected than knurled rolls used for FCAW wires.

Solution: Periodically remove the drive rolls and clean them with a wire brush to eliminate the buildup of drawing compound, dust, and dirt that would affect the pressure and grip the rolls would have on the wire. At the same time, inspect the drive rolls for wear. They do wear out, especially if knurled.

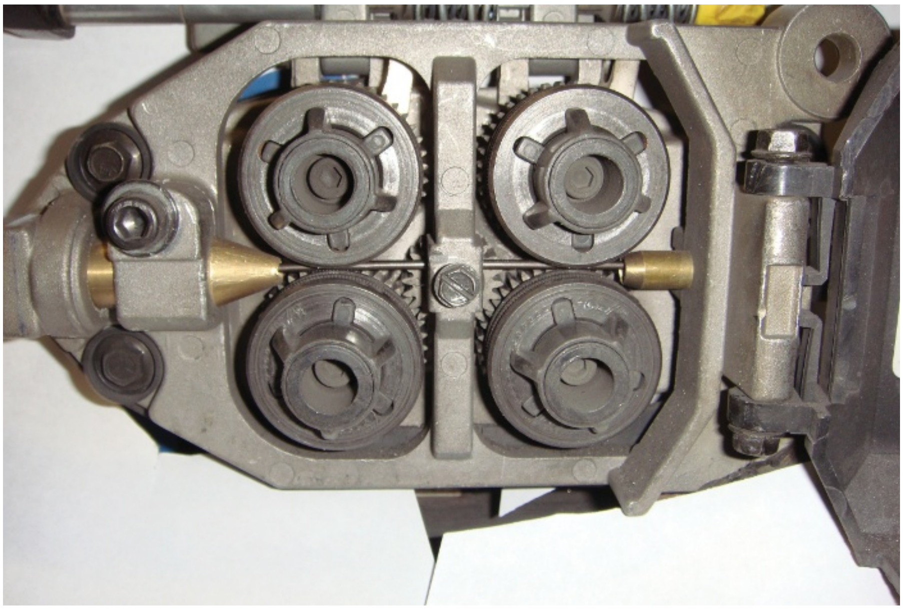

Fig. 1 — Drive rolls develop a feeding problem when they become packed with wire lubricant, dust, and smoke that can cause the wire to slip. This usually causes the operator to tighten the drive tension, creating more problems. Occasional cleaning can help prevent "shaving" the wire when it slips.

❷ **Problem:** Drive roll pressure is too high. It's common, when a feeding problem arises, to tighten the drive rolls to grip the wire better to overcome the problem. This is especially true when using knurled rolls for flux cored wire. Because of its construction, flux cored wire is easy to reshape, from round to oval, with drive roll pressure, and when using knurled rolls the wire develops "teeth." These teeth will start to wear the liner, guides, and tip like a saw. Solid wire, when used with knurled drive rolls, won't change shape like flux cored wire, but will develop the teeth and cause similar wear.

Solution: Periodically, before feeding the wire through the cable/hose assembly, use an air nozzle and shop air pressure to blow out the liner, first from the gun end, then, if convenient, from the feeder end. The amount of small debris blown out of the liner will amaze you. Shavings from the wear and wire have a tendency to pack up the liner at noncontact points and junctions (diffuser/tip). This will cause the wire to chatter or stop feeding altogether. It will also wear the liner out more quickly.

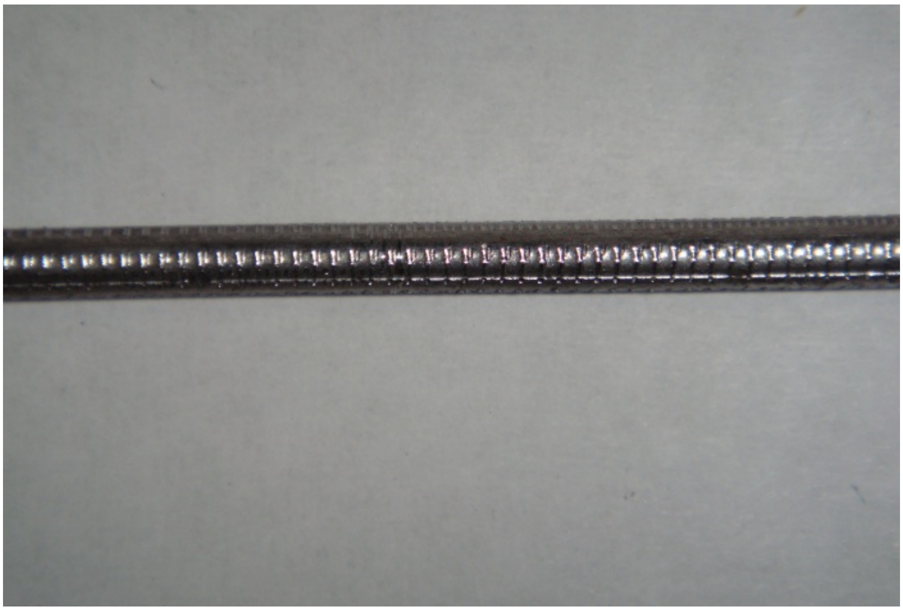

Fig. 2 — Tightening the drive rolls on the feeder, the first response an operator makes when feeding becomes difficult, can create "teeth," particularly on flux cored or soft solid wires. These "teeth" will then wear grooves, over time, in the guides, liner, and tip, compounding the problem.

❸ **Problem:** Worn spring liner. The spring liner used for almost all cable/hose assemblies is removable and replaceable. Almost all spring liners have at least two bends that are constant. One, coming out of the feeder, the other in the gun neck. The wire rubs the same spot and wears a groove in the liner. This acts as a high-friction area as the groove deepens, and the more bends that are permanent increases the drag on the wire, causing it to "bird nest" at the gun inlet or just stop feeding. This is also one cause of the chatter that can frustrate a welder.

Solution: Occasionally, index the liner, remove, and inspect it. A kink in the liner will cause a feeding problem. Blow out the liner guide, turn the liner 90 to 180 deg and reinstall it (you did index it before you pulled it out, didn't you?). This will present a fresh area in the liner to the wear of the moving wire. You will still eventually need to replace the liner, but doing this can extend the life 3 or 4 times what it would normally be.

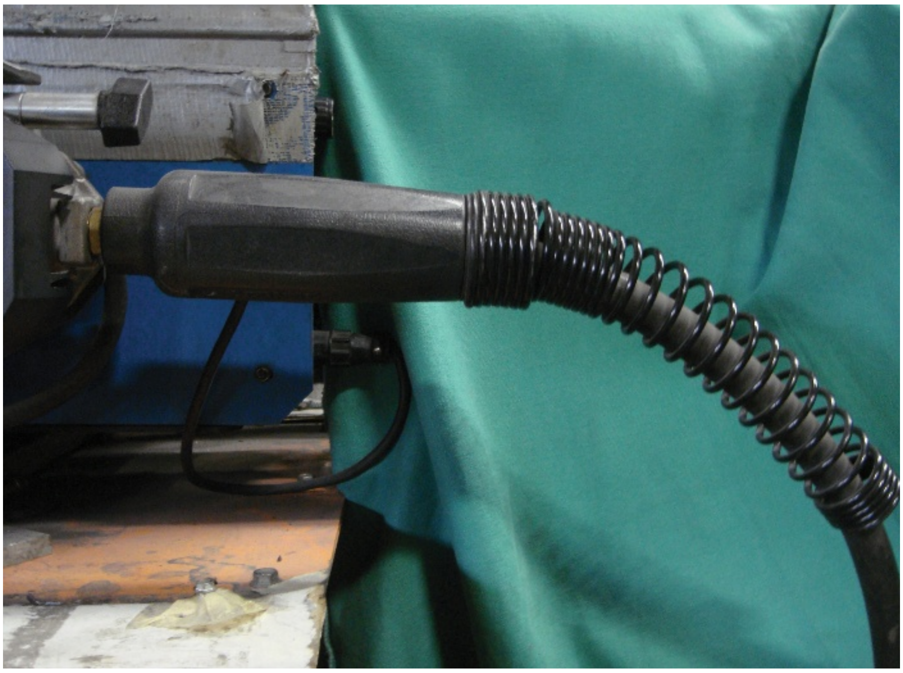

Fig. 3 — Permanent bends in the cable hose/gun assembly, at the outlet of the feeder and in the neck of the gun, always result in a groove in the liner because the wire rides in the same spot with every inch fed through it. Indexing the liner can help prevent excessive wear in these spots and cause the liner to last longer.

❹ **Problem:** Diffuser/tip problems. The most commonly replaced item in a gun assembly is the tip. Because the tip is at the business end of the gun, it receives the lion's share of the abuse from the heat, spatter, and the operator.

Solution: Aside from normal wear causing replacement, the tip is rarely the cause of feeding problems, but does show the results of the problem. If the tip has been replaced and feeding problems persist, then there is almost a guarantee that the problem has developed in one of the previously discussed areas.

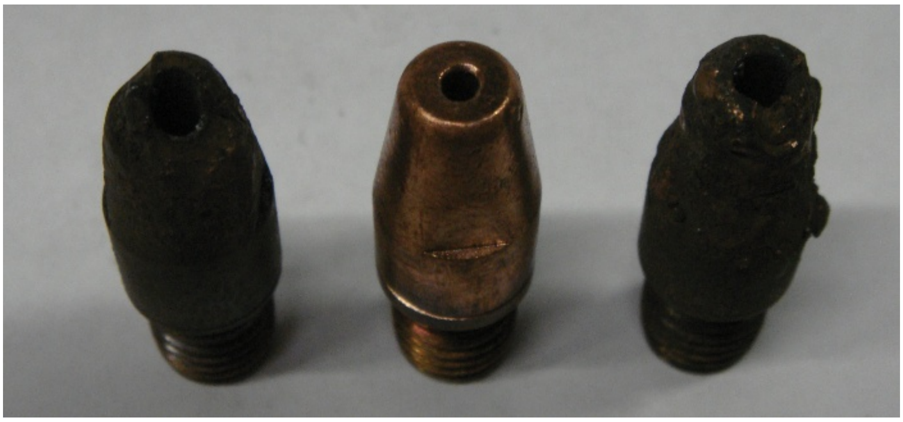

Fig. 4 — The contact tips will almost always show the result of any feeding problem, regardless where it starts, but isn't usually the cause. These tips started out the same size (⅛ in.). High feed rates and excessive drive roll tension, creating teeth on the wire, can result in very short tip life.

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❺ **Problem:** A bad workpiece lead can present itself as a stutter and act like the wire needs voltage or speed adjustment, a lack of shielding gas coverage, liner or tip grab, or base metal contamination, causing porosity.

Solution: Periodically, check the workpiece lead at the power source, wire feeder, and work clamp. A bad workpiece lead can destroy a tip with burn-back and spatter.

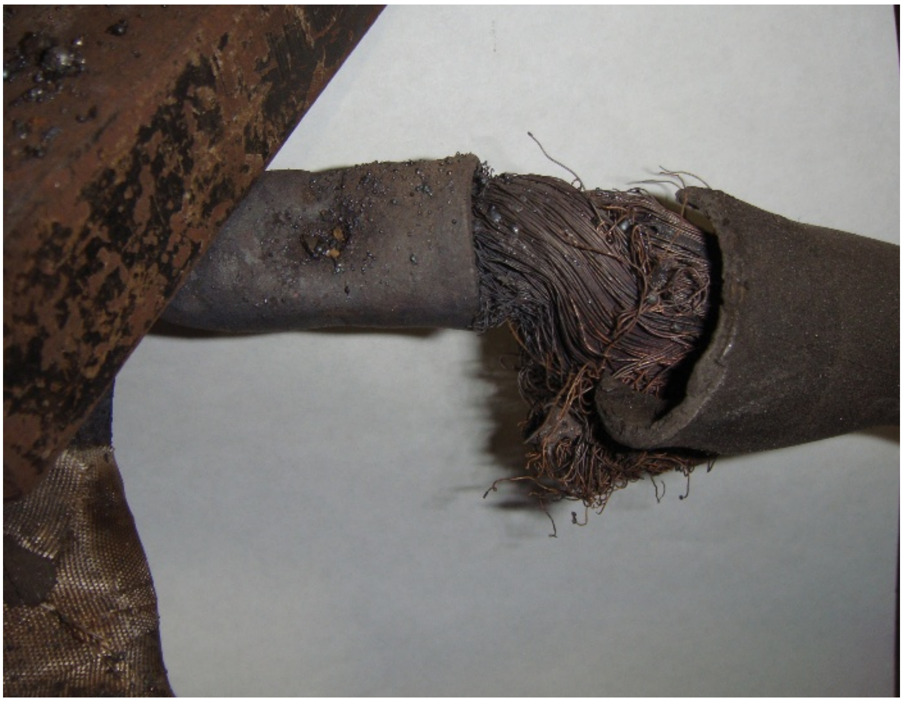

Fig. 5 — A bad workpiece lead will usually manifest itself as a feeding problem, with stutter and spatter usually just before it fails. Check the workpiece lead frequently and keep the connections tight and in good condition.

Maintenance Products

One of the easiest ways to maintain good feeding characteristics, if everything else is right, is with the use of commonly available wire lube and cleaner, good for GMAW and FCAW. Another good idea for preserving the consumables (nozzle and tip) is nozzle dip. These products won't fix drive rolls issues, worn liners, or weak grounds, but when used following the manufacturer's recommendations and the previously mentioned tips, will allow for much longer component life, fewer feeding problems, and many more good days than bad. WJ

DAVID LEE (dlee@weldmold.com) *is technical director, Weld Mold Company, Brighton, Mich.*

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Reserve your sponsorship in one of these upcoming events

AWS Cladding Conference - Minneapolis, MN. May 12-13, 2015

The use of cladding to protect structures from corrosion is growing by leaps and bounds. Weld cladding is a cost effective way to prepare structures and piping for applications such as sour gas, chemical reactors and storage vessels, high temperature power generation equipment, transition joints, and repair. Topics include hot-wire weld cladding, roll bonding, explosive cladding, nanocomposite material, strip cladding, the role of lasers, new materials and more that make cladding a competitive solution. Come network with experts who can help you select the preferred process and materials for your applications.

High Temperature Steels Conference - Chicago, IL, August 2015

Materials used in high temperature application are becoming more complex to achieve the creep strength and corrosion resistance. A range of low alloy, high strength, and austenitic materials are required depending on the application. What choices does the engineer have once the weldability window for high-temperature steels is cut in half? Come and learn from the experts how to manage weldability of P91 steel, dissimilar metal welding, postweld heat treating, selection of weld consumables, the types of weld cracking, and more.

ITSA Thermal Spray for Oil and Gas Conference - Houston, TX, Oct. 2015

Modern drilling and production applications requires advanced coatings for wear and corrosion resistance. New developments in thermal spray materials have been achieved to overcome complex application conditions such as deep water where conditions are hotter and sour. This two-day conference will cover the latest benefits and applications of thermal spraying in the oil and gas exploration, production, refining, and distribution industries. Exhibits will also be shown.

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Using SAW to Weld Creep-Resistant Steels

Controlling bead size, shape, and placement is important when using submerged arc welding to join creep strength-enhanced ferritic steels such as P91

BY MATTHEW A. COX AND WILLIAM F. NEWELL JR.

Submerged arc welding (SAW) has long been used in the fabrication of high-energy and heavy-wall piping. This process is utilized for several reasons including high deposition rates, relatively moderate operator skill requirements, no visible arc flash, and the ability to deposit welds that generally possess very good mechanical and metallurgical properties. Alloying of the fluxes also allows further refinement of weld properties depending on the demands of the application.

Of these advantages, the most appealing one is arguably the high deposition rate. Schedules, available manpower, end user demand, and global competition have forced manufacturers and fabricators to rely heavily on SAW to deposit a relatively large amount of weld metal when compared to other common arc processes. The ability to deposit 10 lb an hour or more can speed the fabrication process considerably. This is normally accomplished by depositing weld beads that are considerable in size and penetration, in addition to high heat input.

Creep Strength-Enhanced Applications

A high deposition, high heat input practice is more common than not for most carbon- and low-alloy steels depending on the application. Lower alloyed materials generally do not encounter complex metallurgical transformations during the heating and cooling cycles of welding. However, in the never ending quest to develop alloys with higher performance, new materials have been developed that are unlike anything that has come before. This is especially true in high-temperature, high-pressure applications (such as in power generation) where creep resistance is a primary design consideration. The development of creep strength-enhanced ferritic steels (CSEF) such as Grade 91 have become a mainstay in designs and applications due to their high creep strength and significant weight savings offered.

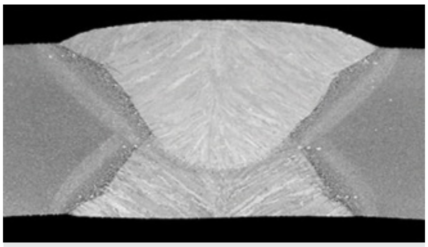


Fig. 1 — High deposition submerged arc weld.

Because SAW is such a simple and easy to use process, many times engineers and operators will overlook the considerations that need to be made when welding CSEF steel with SAW. It is easy to put the correct spool of wire on the feeder, load the correct flux in the hopper, push the start button and be on your way. However, using traditional "hot and heavy" SAW practices, the engineer may find the weld possesses poor mechanical properties when tested. Materials with low ductility in the weld metal and heat-affected zone (HAZ) will likely fail to meet many equipment owners' specifications. Scattered hardness readings may also fall out of specification.

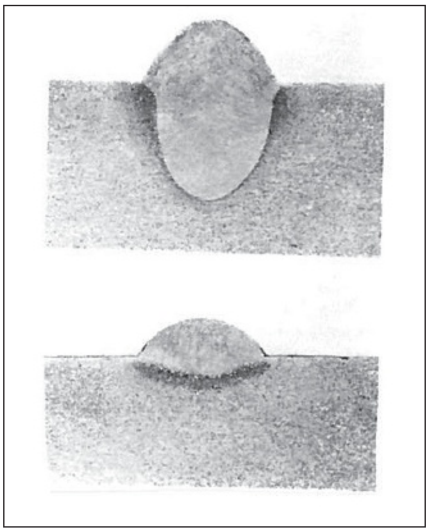
Considerations When Using SAW

For the reasons discussed above, careful consideration must be taken when developing welding procedures for SAW CSEF applications. These advanced materials require special welding and heat treating practices in order to remain safe and reliable during their operating life. One of the most effective and practical ways to achieve the desired metallurgical structures is through regulated deposition rates, heat input and, most importantly, control of bead size, shape, and placement.

Depositing a high amount of filler metal takes a considerable amount of heat input. In most cases this will also lead to a very large and deep penetrating bead that also contributes to a high amount of dilution — Fig. 1. When welding similar metals with a matching filler metal, a high dilution isn't necessarily a problem; however, when welding dissimilar metals, high dilution rates can be a potential hazard. A region of uncertainty will be present along the weld interface adjacent to the HAZ. This hybrid alloy may or may not have the properties one desired. Regardless of dilution rates, a very large bead with high heat input has the potential to degrade the mechanical properties of any metal (Refs. 1, 2). While a slow cooling rate is generally desirable with many metals, the cooling rate of a very heavy bead on a material that already has a 400°F preheat will be far too slow. It can be expected the yield strength, hardness , and impact properties will all be reduced significantly.

Follow a Different Formula

In many cases, a welding engineer would turn to the traditional heat input formula to monitor and predict heat input as well as bead shape. This method should be used with caution,



Figs. 2 and 3 — Each weld bead deposited with an average heat input of 1.78 kJ/mm (45 kJ/in.) (Ref. 1).

as the heat input formula simply measures the electrical energy spent, and does not take into account the effectiveness of that energy or how efficiently it was used. There are several studies that show SAW cross-sectional bead size and penetration can vary a great deal with the same or similar heat input using the traditional formula as illustrated in Figs. 2 and 3.

Research performed by Linde and many others in the past 60 years has shown this to be true in many cases for a variety of processes, not just SAW (Refs. 1–4). The reason for this is there are too many other variables that affect the weld, including the use of constant voltage vs. constant current, preheat, material thickness, electrode extension (this significantly affects I^2R heating), and current density when using different-diameter electrodes and characteristics of different batches of flux.

The Way to Go

An effective way to obtain desirable mechanical properties from welds in CSEF steels is deposit beads of a more conservative size that can be placed accurately and evenly as the joint is filled — Fig. 4. The smaller cross section of these beads also lend themselves to further tempering and promote grain refinement by the heat from subsequent beads. This tempering technique helps the weld metal obtain the desired mechanical properties, especially ductility and toughness. Using such a technique, it is not uncommon to see impact properties at room temperature ranging 40–50 ft-lb or more throughout the weld metal and HAZ. These values are only a fraction of what can be obtained with other steels, but they are considered very good for CSEF materials. WJ

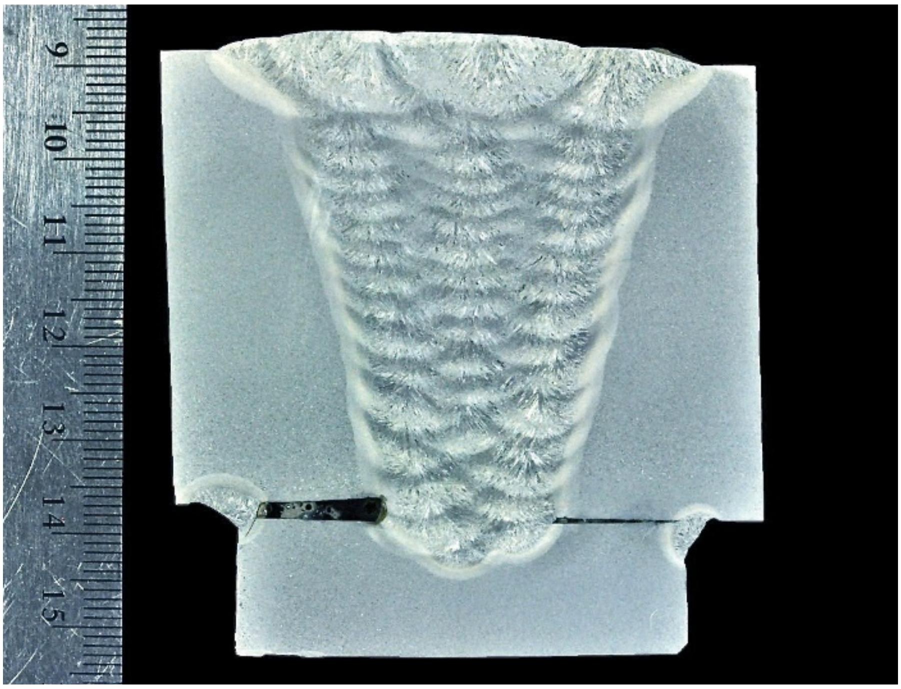


Fig. 4 — 2.0-in.- (50-mm-) thick Grade 91 SAW weldment using consistent and evenly placed beads.

Conclusion

Submerged arc welding is an excellent process for joining CSEF materials, but careful consideration needs to be taken into account when developing procedures and executing production. Submerged arc welding has always lured fabricators with promises of high deposition rates and relatively moderate operator skill. While this is true in many cases, a CSEF application requires diligence by the engineers and production personnel to develop procedures and techniques that obtain welds with controlled bead size, profiles, and the desired properties.

Acknowledgment

The authors would like to acknowledge James Hales, president of Special Welding and Machining, LLC, for his contributions.

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Tulsa Welding School-Jacksonville Equips Hundreds for Good-Paying Jobs in Industry

TWS-Jacksonville uses its many resources to provide a comprehensive training experience covering most environments students will encounter in the field

BY HOWARD M. WOODWARD

Tulsa Welding School (TWS) has locations in Tulsa, Okla., Jacksonville, Fla., and Houston, Tex. The Tulsa facility has trained men and women for professional, entry-level careers since January 1949. The Jacksonville school opened in 2001, and the Tulsa Welding School & Technology Center opened in Houston, Tex., in December 2014.

The training programs at the schools are designed to meet employers' needs by providing students with the essential technical knowledge and laboratory experience needed to get a good job, based on local industry feedback in the welding, heating, ventilation, air-conditioning and refrigeration (HVAC/R) industries.

The 41,000-sq-ft Jacksonville training facility features a welding lab providing 220 welding booths — Fig. 1. Each booth is equipped with either a Lincoln Invertec® V-350 Pro, Invertec® 275-S, or Precision TIG 275, four pack racks of Flextec® 450, and Active 8 wire feeders to fulfill the needs for a wide variety of projects. Additionally, the lab provides students with the tools and equipment currently used in the industry. They work with the latest multiprocess welding equipment and learn how to properly set the machines based on each project's specifications.

The Cutting Lab has 20 pipe Watts® beveling stations, 20 oxyfuel track cutting machines, and carbon arc gougers, and DeWalt® grinders. In this facility, students learn how to make straight and beveled cuts on plates and beveled cuts on 2-, 5-, and 10-in. pipes.

"Safety is a priority here at TWS Jax," said Dion Thornhill, academic dean and advisor to the school's AWS Student Chapter, "so each student learns how to properly care for and operate all of the machinery. Also, every student is offered personal protective equipment that is specially designed for welders by Lincoln Electric and all of the welding booths are fitted with adjustable-height worktables to allow everyone to work comfortably with less strain."

The lab also includes an Advanced Training Module Area to provide students with experience working in confined spaces such as welding on elevated I-beams, from a staircase, and in confined areas.

Instructors

With student-to-instructor ratios of 20-to-1 in the lab and 30-to-1 in the classroom, students receive sufficient personal attention. All of the instructors are professionals who have at least five years of experience in the field, including the nuclear, railroad, water treatment, and fabrication industries — Figs. 2, 3. Each is well qualified to relate to their students and teach to their diverse occupational interests.

"Our instructors take pride in seeing their students master the various welding concepts," Thornhill said. "Several of the instructors are graduates of Tulsa Welding School. This bond enhances staff camaraderie with the students."

The instructors provide students with one-on-one instruction on processes they will encounter in the field. This enables them to monitor each student's progress on a daily basis.

Students are challenged by their instructors to go beyond performing routine structural or pipe welding projects. As each student progresses, the instructor provides more challenging real-world projects to help them hone-in on their desired career path. These projects range from creating small ornamental items, to larger fabricated and structural pieces, all carefully developed using blueprints and Welding Procedure Specifications (WPSs) — Fig. 4. Students experiencing difficulty with their studies can get remedial help from a dedicated instructor and classroom facility. And, for those who do not have a high school diploma, TWS offers free classes to help them pass their GED test.

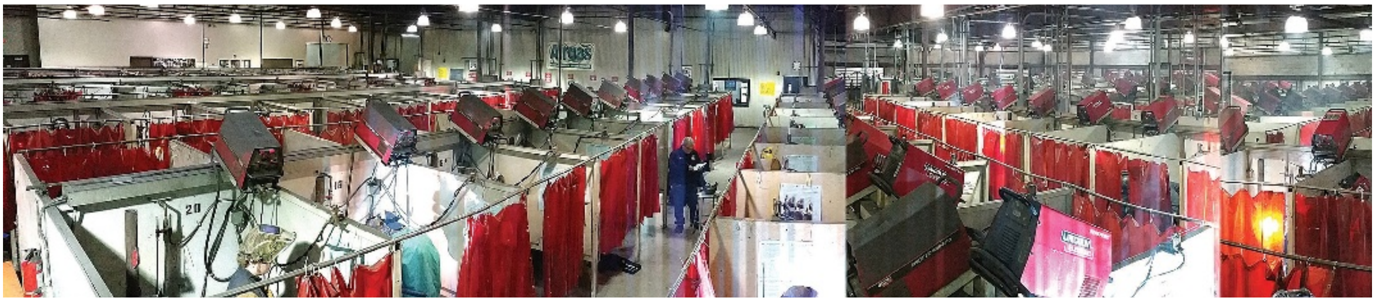

Fig. 1 — A bird's eye view of the welding lab.

Fig. 2 — The welding instructors are (from left) David Masiello, George Moeller, Jon Latimer, Freddie Westbrook, Matt Wilson, Brian Akers, Director of Training Jack Dulls, Mike Merrilees, Nick Diotte, and Sean Lawler.

Classes

The Professional Welder program prepares its graduates for entry-level positions in the structural, pipe, and thin-alloy, and/or pipeline welding industries with 80% of students' time spent working in the labs. The key welding processes used include shielded metal arc welding (SMAW), gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), high-frequency GTAW, and flux cored arc welding (FCAW). The program consists of ten three-week phase courses for a total of 30 weeks, 25 semester credit hours, and 750 contact hours of instruction. Many students opt for taking the Professional Welder program since it helps them become qualified for more job opportunities. Upon successful completion of this program, students receive a diploma.

Outline of the Professional Welder Program

Phase 101 — Introduction to Welding

This class presents an overview of welders' career responsibilities, work safety practices, career success skills, importance of job attitudes and work ethics, equipment maintenance, beginning review of welding symbols and corresponding welds, cutting torch operations, procedures to clean and evaluate welds, cut and prepare metal plate, perform overlap beads in various plate positions, and begin fillet welds in T-joints.

Phase 102 — Structural Welding I

Students will learn more about the SMAW process, use of welding codes, rod selection, basic blueprint reading, calculating dimensions, and completing layouts. Introductions to Learning Resource Center, research project instruction, and career success skills as well as safety and operational procedures of plasma and carbon arc cutting. Perform plate welding in various positions using 7018 electrodes and perform plasma and carbon arc cutting.

Phase 103 — GMAW and FCAW

Interpretation of pipe and fitting markings, metal color codes, pipe welding symbols, pipe diagrams and welds, sketch isometric drawings, GMA and FCA welding procedures, perform plate welding in various positions (2F, 2G, 3G) using GMAW and FCAW, and completion of a research project.

Phase 104 — Structural Welding II

Advanced projects beyond Phase 102 in blueprint and layout, perform plate welding in various positions (2G, 3G, 4G) using 6010 electrodes for root pass and 7018 electrodes for the remainder. Also presented is pipe bevel preparation.

Phase 105 — Basic Pipe Welding

Techniques of basic pipe fitting, use of 90s, Ts, flanges, valves, take offs, pipe blueprints, sketches, templates, and uphill welding techniques on pipe. Perform pipe welding with SMAW with 6010 electrode stringer and 7018 electrode remainder in 2G and 5G pipe positions.

Phase 106 — Pipe Welding I

Students will receive an overview of GTAW equipment and procedure setup, metals identification, tungsten safety, and preparation. Perform 6010 electrode root and 7018 electrode fill and cap in 6G position. Perform GTAW stringer and hot pass on T-plate. Perform GTAW root and 7018 fill and cap in the 2G and 6G pipe positions.

Phase 107 — Pipe Welding II

Operation requirements for portable equipment, weld test lab procedures and testing approaches, perform mild steel GTA welding on pipe in various positions (2G, 5G, 6G) using GTA stringer, fill, and cap.

Phase 108 — Advanced Pipe Welding

Advanced pipe welding projects and industrial applications, concentration on performing stainless steel GTA welding on mild steel and using multiple pipe sizes and schedules in various pipe positions (2G, 5G, 6G).

Phase 109 — High-Frequency GTAW and/or Pipeline Welding

Thin alloy selection of tungsten types for aluminum and stainless steel, methods to maintain clean work environment, procedures for heat settings on thin-gauge applications, purging stainless steel plate, weld cleaning on aluminum and stainless steel, perform aluminum and stainless steel welding on plate using GTAW in various positions with different rod sizes. Pipeline selection of rod size, layout procedures for pipeline fitting, coating

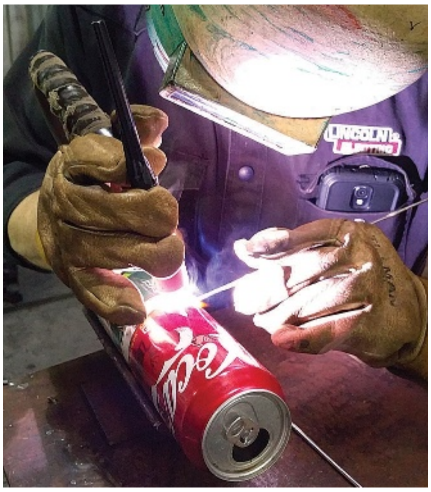

Fig. 3 — Jack Dulls, director of training, shows students how to weld thin metal using gas tungsten arc welding.

types and electrolysis prevention with anode protection, perform SMAW downhill stringer, fill, and cap in 5G and 6G positions and inverted T. Also, a student may elect to specialize in only high-frequency (H-F) GTAW or pipeline welding or a combination of both specialties.

Phase 110 — Career Preparation

This is the student's final phase prior to introduction into the employment market with options for shop or field welding. Included are instruction in application for employment, preparing a résumé, weld testing rigors, proper appearance, and job attitude.

Lab competencies are 2-in. 6G GTAW all the way out, structural plate with GMAW root and FCAW fill and cap, 5G GTAW root and hot pass with 7018 fill and cap, and 6G pipe welding using 6010 and 7018 fill and cap. All welds must pass a guided bend test.

Working with Industry

"In an effort to ensure the TWS-Jacksonville programs meet the needs of local and national employers," said Thornhill, "we developed an additional training called Phase 11. The sole purpose of Phase 11 is to prepare graduates to meet the demands of a specific employer's hiring needs. There is no charge to the employer or the graduate for this training."

After obtaining the Welding Procedure Specifications from an employer, the director of training, academic dean, and career services director discuss the timeframe of Phase 11. Once a timeframe is determined, graduates are allowed to enroll and participate. After Phase 11 training, the employer's quality control person and/or Certified Welding Inspector visits the school to observe the graduates as they work and to examine their welds. The employer then interviews the candidates to make the job offer. "Often our graduates are offered perks including relocation reimbursement, stipends, and medical benefits," said Thornhill. "Currently, the school partners with a number of companies to develop these practical welding practices."

Diverse Population

As the need for welders continues to grow, so does the number of women interested in becoming a vital part of the welding industry. Tulsa Welding School provides a nurturing educational environment that allows candidates of all backgrounds interested in learning the art of welding to easily blend into the school's welcoming culture. Notably, according to Tulsa Welding School's current population, veterans of the U.S. military services comprise 25% of the student body — Fig. 4. Thornhill said, "TWS gives veterans a chance to settle back into civilian life by placing them in a program that focuses on the skills they need to obtain well-paying jobs in industry. Also," he added, "based on the current population, nearly 2.5% of students enrolled in Tulsa Welding School programs are female."

Fig. 4 — Veteran Jonathan Pinkney, a former student, displays his custom-designed Marine Corps welding helmet.

Fig. 5 — Jack Dulls (left), director of training, and Academic Dean Dion Thornhill (right) help Top One Welder graduate student Thomas Wright hold his prize.

Student Incentives

Tulsa Welding School has incorporated a number of programs to encourage students to become more involved in shaping the school's culture. These programs provide them with opportunities to showcase their welding, leadership, and teamwork skills.

The Top Welder Program allows the staff to acknowledge students who achieve the highest grades and best attendance in each phase. The winners receive a "Top Welder" T-shirt and a sticker to commemorate their accomplishments. As an added bonus, the student who receives the highest grade point average, achieves a 95% attendance rating or better, and has the most Top One Awards of his or her graduating class, can choose either a Lincoln Electric SP-140T GMA or AC 225 SMA welding machine. The awardees are presented their recognitions in the presence of their peers to help reinforce the school's motto: *Nothing but Excellence* — Fig. 5.

Fig. 6 — The Tulsa Welding School Student Chapter, chartered in December 2014, boasts one of the largest memberships in the nation.

In addition, the school provides students with a support team dedicated to help them achieve success. This includes financial aid assistance to those who qualify, housing assistance, temporary job assistance, and career services assistance.

Complementary Studies

As part of the school's Electro Mechanical Technologies Program supporting HVAC/R careers, the welding lab provides students experience in wiring in simulated residential and commercial environments. Solar Technologies is a part of this program. The course provides an overview of the photovoltaic science and an introduction to the fundamentals of solar energy. The module covers the scope of solar energy systems' conceptual, mechanical, and electrical design, with an emphasis on wiring and electrical issues. The last class is Advanced Troubleshooting Techniques. Its goal is to ensure students have acquired the necessary skills to succeed as an entry-level technician, prepared to qualify for the EPA Section 608 Certification.

AWS Student Chapter

The Tulsa Welding School in Jacksonville is home to one of the newest and largest AWS Student Chapters in the country, affiliated with the AWS North Florida Section — Fig. 6.

Chartered in Dec. 2014, it has more than 450 members. These students, led by Advisor Dion Thornhill, have set several goals to make them become very active and visible in the Jacksonville community. Their plans include forming alliances with Habitat for Humanity, the Boy Scouts of America, and Future Farmers of America to provide opportunities for them to mentor and prepare the younger generation for a future in welding while enhancing their own skills. Students also can participate in Student Appreciation Day, SkillsUSA welding competitions, and Welding Wars, a school-wide welding competition for students in the various phases to compete against each other in a variety of welding challenges.

Visitors are invited to tour the campus during Friends and Family Day when they can watch the students showcase their welding skills. WJ

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Shielding Gases for Gas Metal Arc Welding

The primary function of the shelding gas in gas metal arc welding (GMAW) is to exclude the atmosphere from contact with the molten weld metal. This is necessary because most metals, when heated to their melting point in air, tend to form oxides and, to a lesser extent, nitrides. Oxygen also reacts with carbon in molten steel to form carbon monoxide and carbon dioxide. These varied reaction products may result in weld discontinuities such as slag inclusions, porosity, and weld metal embrittlement. Reaction products are easily formed in the atmosphere unless precautions are taken to exclude nitrogen and oxygen.

Beside providing a protective environment, the shielding gas and flow rate also have a pronounced effect on the following:

1. Arc characteristics
2. Mode of metal transfer
3. Penetration and weld bead profile
4. Speed of welding
5. Undercutting tendency
6. Cleaning action
7. Weld metal mechanical properties.

The electrode manufacturer is generally a good source of information on selecting the optimum shielding gas for use with its electrodes.

Table 1 shows the principal gases used in the spray arc mode of GMAW. Most of these are mixtures of inert gases that may also contain small quantities of oxygen or carbon dioxide. Table 2 lists gases used for short-circuit GMAW.

Table 1 — GMAW Shielding Gases for Spray Transfer

Metal	Shielding Gas	Characteristics
Aluminum	100% argon	Best metal transfer and arc stability; least spatter; good cleaning action.
	35% argon-65% helium	Higher heat input than 100% argon; improved fusion characteristics on thicker material; minimizes porosity.
	25% argon-75% helium	Highest heat input; minimizes porosity; least cleaning action.
Magnesium	100% argon	Excellent cleaning action; stable arc.
	Argon + 20–70% helium	Improved wetting; less chance of porosity.
Carbon steel	1–5% oxygen, balance argon	Improves arc stability; produces a more fluid and controllable weld pool; good fusion and bead contour; minimizes undercutting; permits higher speeds than pure argon.
	5–15% carbon dioxide, balance argon	High-speed mechanized welding; low-cost manual welding.
Low-alloy steel	98% argon-2% oxygen	Minimizes undercutting; provides good toughness.
Stainless steel	99% argon-1% oxygen	Improves arc stability; produces a more fluid and controllable weld pool, good fusion and bead contour; minimizes undercutting on heavier stainless steels.
	98% argon-2% oxygen	Provides better arc stability, coalescense, and welding spee-d than 1% oxygen mixture for thinner stainless steel materials.
Nickel, copper, and their alloys	100% argon	Provides good wetting; decreases fluidity of weld metal
	Argon-helium	Higher heat inputs of 50 and 75% helium mixtures offset high heat dissipation of heavier gauges.
Titanium	100% argon	Good arc stability; minimum weld contamination; inert gas backing is required to prevent air contamination on back of weld area.

Table 2 — GMAW Shielding Gases for Short-Circuiting Transfer

Metal	Shielding Gas	Characteristics
Carbon steel	75% argon + 25% carbon dioxide	High welding speeds with minimum melt-through; minimum spatter; clean weld appearance; good pool control in vertical and overhead positions.
	100% carbon dioxide	Deeper penetration; faster welding speeds; high spatter levels.
Stainless steel	90% helium + 7.5% argon + 2.5% carbon dioxide	No effect on corrosion resistance; small heat-affected zone; minimizes undercut.
Low-alloy steel	60–70% helium + 25–35% argon + 4.5% carbon dioxide	Minimum reactivity; excellent toughness; excellent arc stability, wetting characteristics, and bead contour; little spatter.
	75% argon + 25% carbon dioxide	Fair toughness; excellent arc stability, wetting characteristics, and bead contour; little spatter.
Aluminum, copper, magnesium, nickel, and their alloys	Argon, and argon + helium	Argon satisfactory on sheet metal; argon-helium preferred for thicker base material.

Excerpted from the *Welding Handbook*, Vol. 2, 9th Edition, Welding Processes, Part 1.

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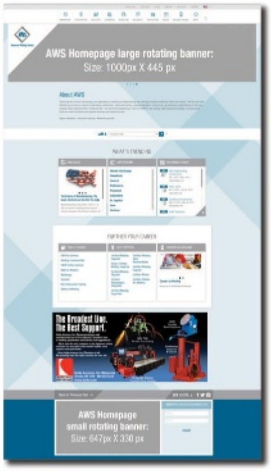

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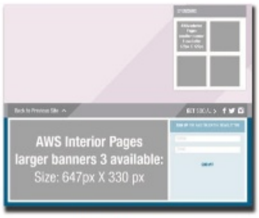

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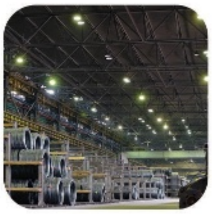

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- Shadow facility auditors, at a minimum, every three years or as requested and more frequently, if needed.
- Review of final Audit Reports and NCRs and provide feedback reports to Director, Accreditation Programs.
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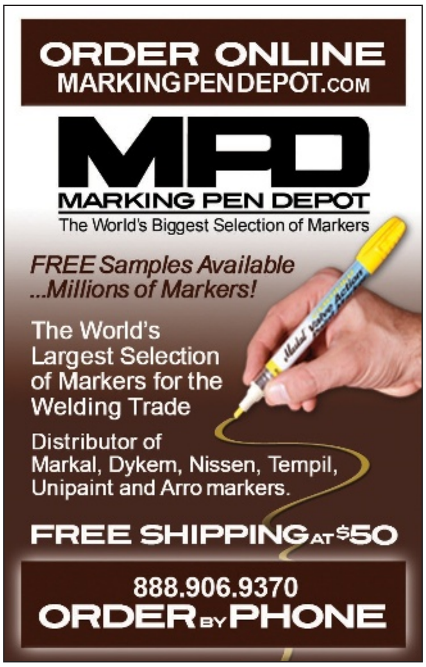
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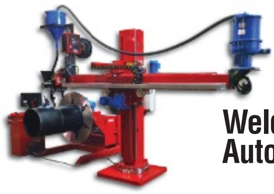

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WELDING RESEARCH

SUPPLEMENT TO THE *WELDING JOURNAL,* MAY 2015
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Creep Rupture Performance of Welds of P91 Pipe Steel

A strong effect of Al content on creep resistance was observed and explained based on weld metal microstructure and precipitation thermodynamics/kinetics

BY X. CHAI, J. C. BUNDY, M. A. AMATA, C. ZHANG, F. ZHANG, S. CHEN, S. S. BABU, AND S. KOU

ABSTRACT

The creep resistance of welds of P91 pipe steel was investigated, focusing on the effect of the Al content in the fusion zone. Two welds were made with significantly different Al contents, one high at 0.455 wt-% and the other low at 0.001 wt-%. The N contents were comparable, 0.035 wt-% in the high-Al weld and 0.043 wt-% in the low-Al one. After postweld heat treatment at 760°C for 4 h, specimens were prepared from inside the fusion zones for creep rupture tests. The high-Al weld showed a much lower creep resistance than the low-Al one. To explain the significant effect of Al on the creep resistance, the microstructure of the welds, especially retained δ-ferrite and nitride precipitates, was examined by optical and electron microscopy and discussed based on either existing data or calculated results of thermodynamics and kinetics. First, the presence or absence of retained δ-ferrite in the martensite matrix was checked and discussed in light of Al as a strong ferrite stabilizer. Second, precipitates in the welds were examined by electron microscopy, including their sizes and compositions, especially the contents of Al, Cr, and V. Third, the formation of the precipitates of AlN, VN, and NbN was further discussed based on the Ellingham diagram, data of the solubility products, and the volume fractions of AlN, VN, and NbN calculated using the thermodynamic software package Pandat.

KEYWORDS

- Creep Resistance • P91 • Aluminum Content • Ferritic Steels • Pipe

Introduction

P91 steel, a modified 9Cr-1Mo steel for use as pipes, is one of the new 9–12% Cr ferritic martensite steels designed to improve creep resistance. P91 steel contains vanadium (V), niobium (Nb), and nitrogen (N) as minor alloying elements to improve the creep resistance by fine precipitates of vanadium carbonitride V(CN) and niobium carbonitride Nb(CN) in a tempered martensite matrix (Refs. 1–9). These precipitates are commonly denoted as MX precipitates, where M stands for V or Nb and X for carbon and/or nitrogen. Regardless of MX, $M_{23}C_6$ carbide precipitates from the martensitic matrix, where M denotes Cr and Fe and C for carbon. In comparison to MX precipitates, $M_{23}C_6$ precipitates are much less stable morphologically at elevated temperatures. At elevated temperatures, they tend to coarsen over time much more significantly than MX precipitates and are thus less able to resist creep by pinning down the movements of dislocations and interfaces, such as prior austenite grain boundaries, prior martensite lath boundaries, and subgrain boundaries (Refs. 5, 10–17). It has been suggested (Ref. 11) that subgrain boundary migration may control the recovery of dislocations and that subgrain boundary hardening enhanced by fine dispersions of precipitates along the internal interfaces is one of the most important strengthening mechanisms in 9–12%Cr ferritic steels (Ref. 12). It is worth noting that David et al. (Ref. 9) and Siefert and David (Ref. 18) have reviewed the weldability of new alloys developed for advanced fossil power plants including ferritic and austenitic alloys.

The production of P91 steel usually involves normalization at about 1050°C, air cooling to the room temperature to form martensite, and then reheating at about 750°C to temper the martensite (Ref. 19). The evolution of the type and size distribution of precipitates during the above preweld tempering condition also controls the Type IV creep failure observed in the heat-affected zone (HAZ) (Refs. 9, 20, 21). The present study pertains to the microstructure evolution in the fusion zone.

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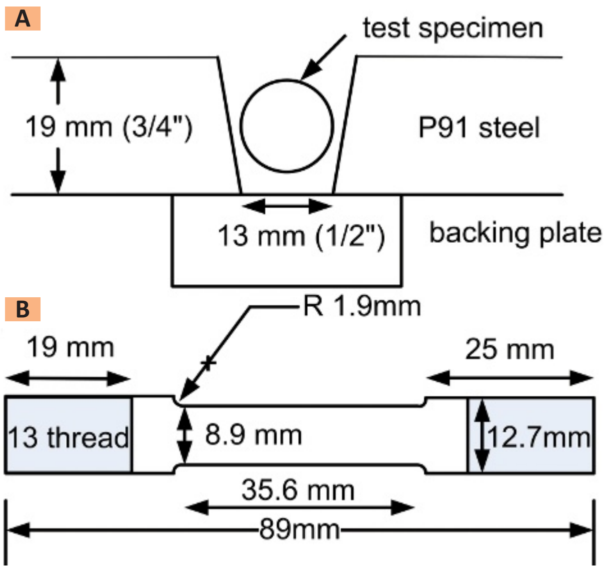


Fig. 1 — Designs for welding and creep-rupture testing. A — Joint design for butt-joint welding; B — creep-rupture test specimen.

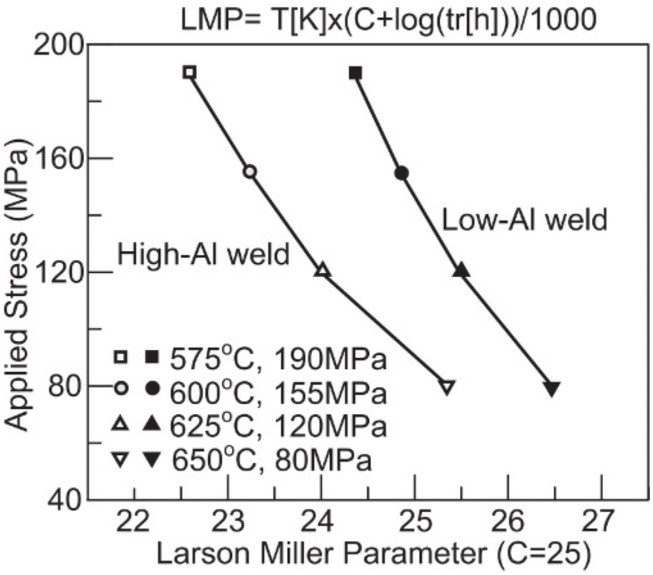


Fig. 2 — Results of creep-rupture tests (Table 3) showing much lower creep resistance of high-Al weld by plotting applied stress vs. Larson-Miller parameter (LMP), where T[K] is temperature in degrees Kelvin and tr[h] is time to rupture in hours.

δ-ferrite is the first solid phase to form during solidification, that is, the primary solidification phase, and it transforms to austenite γ upon further cooling. However, the δ → γ transformation may not be complete in many alloy compositions. This phenomenon had been observed in self-shielded flux cored arc welds containing high concentration (1.8 wt-%) of aluminum (Al) (Ref. 22).

This can also be seen from the study of Mayr et al. (Ref. 23) on a 9-Cr steel similar to P91 by in-situ X-ray diffraction using synchrotron radiation. They showed that δ-ferrite is nucleated upon heating (at 10 K/s) the steel to 1210°C (1483 K) and the amount of δ-ferrite was 19% upon further heating into the δ + γ region to the peak temperature of 1300°C (1573 K). Upon cooling, the δ-ferrite transformed back to austenite but the transformation was incomplete, resulting in about 2% retained δ-ferrite when the martensite transformation started. Thus, it is likely in welding P91 steel to find retained δ-ferrite in the martensite matrix in the fusion zone as a result of cooling during solidification and in the HAZ as a result of cooling after reheating into the δ + γ region.

The presence of δ-ferrite in the fusion zone of P91 steel has been reported (Ref. 24). The δ-ferrite tends to be elongated during creep rupture test near the fracture surface (Ref. 3). Since δ-ferrite is much softer than the surrounding martensite matrix, it can reduce the creep resistance of the fusion zone significantly (Refs. 9, 25).

For power plant applications, the weld metal, beside good creep resistance, needs to have adequate toughness to meet pressure test and other requirements at the room temperature, e.g., to withstand transient stresses during shutdown periods, as pointed out by Arivazhagan et al. (Ref. 6), Sireesha et al. (Ref. 7), and Francis et al. (Ref. 8). Arivazhagan et al. (Ref. 6) and Sireesha et al. (Ref. 7) suggested that reduction in Nb, N, and Si contents improves toughness, but the Ni content has to be adjusted such that the lower critical temperature (A_{C1}) temperature does not fall below the postweld heat treatment (PWHT) temperature. The need to balance filler material composition to restrict the occurrence of δ-ferrite and ensure a fully martensitic structure in the fusion zone has also been emphasized (Refs. 9, 25).

The effect of Al on the creep resistance of welds of P91 steel has not been investigated so far. An experimental study unrelated to welding was conducted by Naoi et al. (Ref. 26) on 9Cr-0.5Mo-1.8W steel, which is somewhat similar to P91 steel. They observed that increasing the Al content improved the toughness of 9Cr-0.5Mo-1.8W steel at the room temperature. This improvement was attributed to grain refining caused by Al nitride precipitates. However, they also reported that the Al addition reduced the creep resistance. A computational study unrelated to welding was conducted by Magnusson et al. (Ref. 27). Their calculations showed that the Al additions to P91 steel could reduce the creep rupture life by a factor of six.

The present study was conducted to

Table 1 — Nominal Composition of P91 Steel (Ref. 29)

Element	C	Mn	P	S	Si	Cr	Mo	V	Nb	N	Al	Ni
Min wt-%	0.08	0.30	–	–	0.20	8.00	0.85	0.18	0.06	0.030	–	–
Max wt-%	0.12	0.60	0.020	0.010	0.50	9.50	1.05	0.25	0.1	0.070	0.04	0.40

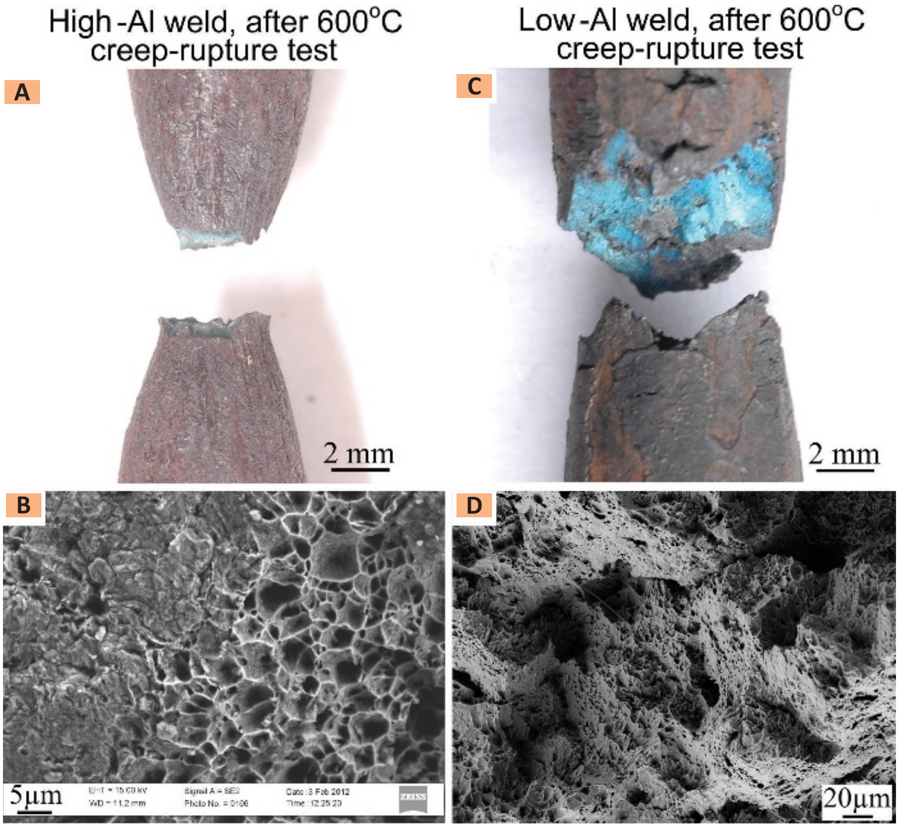

High-Al weld, after 600°C creep-rupture test
Low-Al weld, after 600°C creep-rupture test
A
C
2 mm
2 mm
B
D
5µm
20µm

Fig. 3 — *Weld specimens after creep rupture tests at 600°C. A, C — Macrographs showing much more necking with high-Al weld; B, D — SEM images of fractured surfaces showing clear microvoids characteristic of ductile fracture with high-Al weld.*

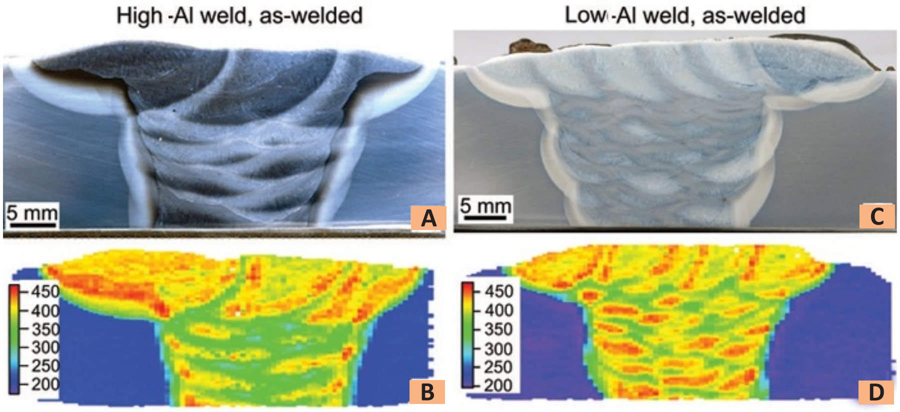


Fig. 4 — *Transverse macrographs and hardness distributions in high- and low-Al welds in as-welded condition. A, C — Transverse macrographs; B, D — microhardness maps.*

Table 2 — Measured Composition of Welds

Element	High-Al Weld wt-%	Low-Al Weld wt-%
C	0.114±0.004	0.117±0.008
Mn	1.025±0.025	0.55±0.01
P	0.007±0.001	0.013
S	0.004	0.009±0.001
Si	0.11±0.01	0.34±0.01
Cr	8.09±0.2	8.22
Mo	0.865±0.065	1.06±0.01
V	0.165±0.005	0.28±0.01
Nb	0.047±0.004	0.051±0.001
Al	0.455±0.035	0.001
N	0.035±0.001	0.043±0.001
O	0.028±0.003	0.1±0.005
Ni	0.04	0.72±0.01
Cu	0.04	0.04

investigate the effect of Al on the creep resistance of the welds (the fusion zone) of P91 steel. The addition of Al to the welding consumable for P91 steel is intended to significantly lower the oxygen content in the weld metal, which is known to enhance the toughness of steel welds (Ref. 28). It is essential to know how the Al addition affects the creep resistance of the weld metal.

Experimental Procedure

The nominal composition of P91 steel is shown in Table 1 (Ref. 29). P91 steel is for fabrication of pipes. A large plate, e.g., 19 mm (¾ in.) in thickness, can be bent and welded along the longitudinal joint to make a pipe, and the specimens for creep rupture tests can be prepared from the weld metal inside the fusion zone. However, in order to follow AWS A5.29/A5.29M: 2010, *Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding* (Ref. 30), the butt joint design in Fig. 1A (which is consistent with Fig. 3 in the AWS specification) was used. A root opening was provided between the two plates to allow multipass welding with the use of a filler metal. A piece of P91 steel 13 mm (½ in.) in thickness and 32 mm (1¼ in.) in width was used as a backing plate.

Two welding consumables were used to weld P91 steel. One was a commercially available covered electrode, E9015-B9 H4R, for shielded metal arc welding (SMAW), and the other was an experimental tubular electrode for flux cored arc welding (FCAW). Shielded metal arc welding was conducted with an average current of 140 A, an average voltage of 22.5 V, and a welding speed of 2.88 mm/s (6.8 in./min) in 33 passes, and the linear heat input was calculated as 1.09 kJ/mm (27.8 kJ/in.). Flux cored arc welding, on the other hand, was conducted with a mixture of Ar and CO_2 for shielding and with an average current of 260 A, an average voltage of 27 V and a travel speed of 4.23 mm/s (10 in./min) in 13 passes, the linear heat input can be calculated as 1.66 kJ/mm (42.2 kJ/in.). The preheat and interpass temperatures were 260°C (500°F) for both welding processes. The fewer passes in FCAW were because the electrode was designed for welding with a relatively high welding current. Differences in the thermal cycles due to heat input

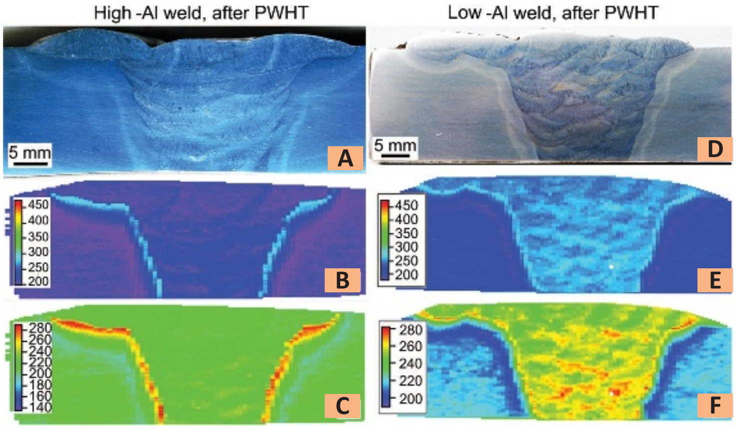


Fig. 5 — Hardness maps on welds after postweld heat treatment showing lower hardness in fusion zone of the high-Al weld than that of the low-Al weld. A, D — Transverse macrographs; B, E — microhardness maps; C, F — hardness scale changed.

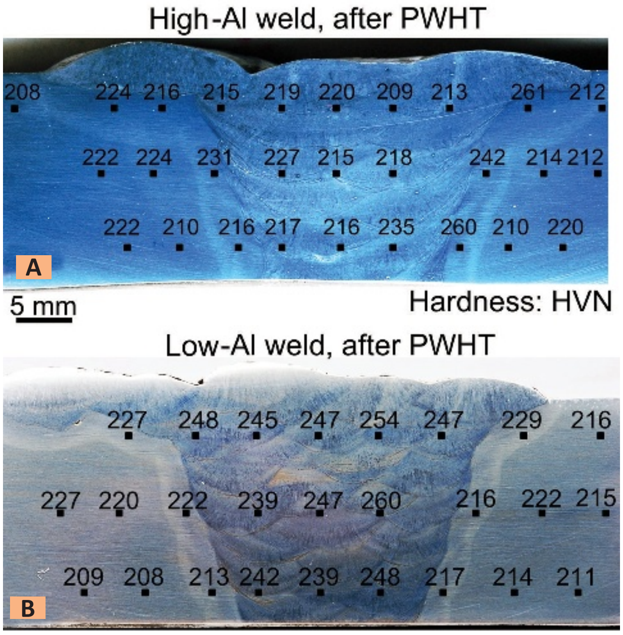


Fig. 6 — Hardness measurements after postweld heat treatment showing lower hardness in the high-Al weld than in the low-Al weld. A — High-Al weld with an average hardness of 219 HV in fusion zone; B — low-Al weld with an average hardness of 247 HV in fusion zone.

are likely to affect the weld metal precipitation, but the large differences in chemical composition are expected to overshadow the effect of different heat inputs. Chemical analysis was performed on “undiluted” weld metal. Most element determinations were made using optical emission spectroscopy (Bruker-Quantron Q8 Magellan). Nitrogen and oxygen were determined using the fusion method (LECO TC-436), and carbon was determined using the combustion method with a LECO CS-200 instrument.

Microhardness measurements were conducted on weld specimens in the as-welded condition and after PWHT at 760°C (1400°F) for 4 h, which is in the suggested PWHT temperature range (730° to 770°C) for P91 steel welds by David et al. (Refs. 9, 18). Sireesha et al. (Ref. 7) also found PWHT at 760°C significantly improved the fusion zone toughness and Silwal et al. (Ref. 31) found PWHT at the same temperature significantly improved the HAZ toughness. Microhardness measurements were conducted automatically using a LECO AMH-43 system with computer-controlled scanning of the weld specimen (Ref. 32). Additional microhardness indentations were made manually at selected locations in the welds with a Tukon 1102/1202 Knoop/Vickers automated hardness tester from Wilson Hardness.

After PWHT, specimens for creep rupture tests were prepared according to the design shown schematically in Fig. 1B. Essentially, rods 13 mm (0.5 in.) in diameter and 89 mm (3.5 in.) long were machined from the fusion zone in the longitudinal direction such that the rod axis was along the centerline of the fusion zone. The mid-section of the rod was reduced by machining to provide a 35.6-mm gauge length of 8.9 mm diameter. Threads were provided at the two ends of the rod to allow connection to the fixtures of the test machine.

Creep rupture tests were conducted in air in standard creep rupture frames at AMC Vulcan Laboratories of Birmingham, Ala. The tests ranged from 190 MPa (27.6 ksi) at 575°C to 80 MPa (11.6 ksi) at 650°C and lasted up to 5000 h. These ranges were selected based on the expected service temperatures and the stress levels estimated for rupture to occur in one thousand hours in the base metal. The yield stress of P91 steel, either the base metal or the weld metal, is over 300 MPa at 575°C and 200 MPa at 650°C (Ref. 33). These are well above the 190 MPa stress level applied in the creep rupture test at 575°C and the 80 MPa stress level at 650°C.

Results and Discussion

The chemical composition of the high-Al weld made by FCAW is shown in Table 2. The 8.09 wt-% Cr and 0.865 wt-% Mo are close to the nominal composition of 8.75 wt-% Cr and 0.95 wt-% Mo of P91 steel (Table 1). The C, V, and Nb contents were 0.114, 0.165, and 0.047 wt-%, respectively. In addition, the weld contained 0.455 wt-% Al and 0.035 wt-% N.

The chemical composition of the low-Al weld made by SMAW is also shown in Table 2. The fusion zone contained 8.22 wt-% Cr and 1.06 wt-% Mo, again close to the nominal Cr and Mo contents of P91 steel, respectively (Table 1). The C, V, and Nb contents were 0.117, 0.28, and 0.051 wt-%, respectively. The N content was 0.043 wt-%, comparable to that of 0.035 wt-% in the high-Al weld made by FCAW. However, unlike the high-Al weld, it was nearly Al free (0.001 wt-% Al).

Creep Rupture Tests

Table 3 shows the results of creep rupture tests of the high- and low-Al welds. As shown, the high-Al weld lasted much shorter in creep rupture tests before failure, up to about 300 h as compared to about 5000 h for the low-Al welds. This difference is consistent with the adverse effect of Al on the creep resistance of P91 steel (Ref. 27) and 9Cr-0.5Mo-1.8W steel (Ref. 26) reported in previous studies unrelated to welding.

In Fig. 2, the applied stress is plotted vs. the Larson Miller Parameter (LMP) defined as follows:

$$LMP = \frac{T[K] \times (C + \log(\mathrm{tr}[h]))}{1000} \quad (1)$$

where $T[K]$ is temperature in degrees Kelvin, C is a constant taken as 25, and $\mathrm{tr}[h]$ is time to rupture in hours.

As expected, the curve for the high-Al weld is significantly more to the left, indicating its much lower resistance to creep rupture as compared to the low-Al weld.

Considerable necking occurred before rupture in all the high-Al weld specimens down to 80 MPa. Figure 3A shows necking in the specimen tested at 600°C and 155 MPa, which is consistent with the low creep resistance of this specimen, that is, significant deformation under tensile loading at the test temperature. According to Table 3, this specimen had a 51.4% elongation and 87.1% reduction in cross-sectional area. The SEM image of the fracture surface in Fig. 3B reveals clear dimples and hence the ductile nature of failure, again consistent with the low creep resistance of the specimen.

Only slight necking occurred in the low-Al weld under identical test conditions as can be seen in Fig. 3C, which is consistent with the high creep resistance of the specimen. According to Table 3, this specimen had a 13% elongation and 29.1% reduction in cross-sectional area. The SEM images of the fracture surface in Fig. 3D reveal no clear dimples like those typical of ductile failure (Fig. 3B), again consistent with the high creep resistance of the specimen.

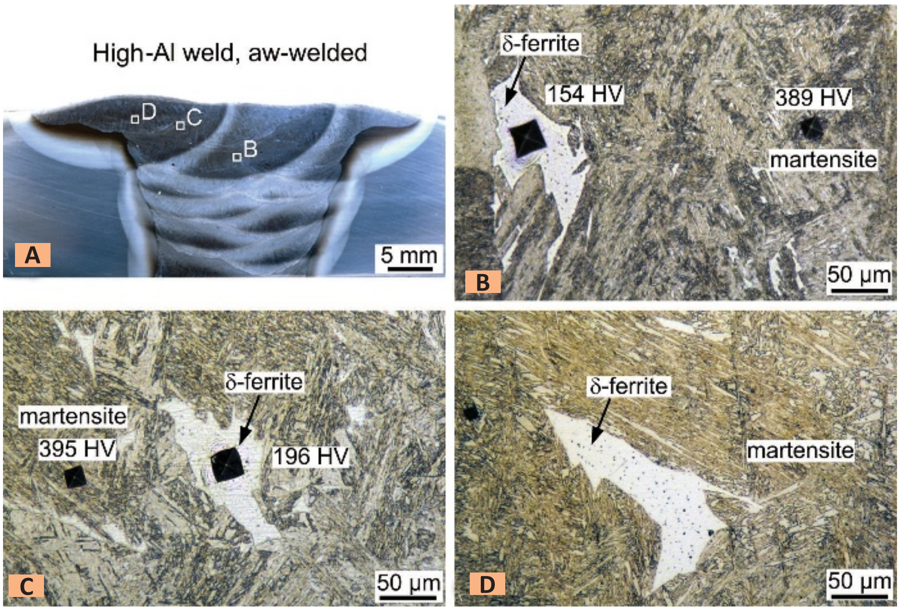


Fig. 7 — Presence of soft δ-ferrite in harder matrix of martensite in high-Al weld in as-welded condition. A — Transverse macrograph of weld; B — optical micrograph at point B in A; C — at point C; D — at point D.

Table 3 — Results of Creep Rupture Tests of the High-Al Weld and the Low-Al Weld

Weld	Temperature (°C)	Stress (MPa)	Rupture (h)	% Elong	% RA
High-Al weld	575 (1067°F)	190	41.4	35.6	82.0
Low-Al weld	575 (1067°F)	190	5110	11.3	30.6
High-Al weld	600 (1112°F)	155	41.1	51.4	87.1
Low-Al weld	600 (1112°F)	155	2875.2	13.0	29.1
High-Al weld	625 (1157°F)	120	52.2	43.8	82.5
Low-Al weld	625 (1157°F)	120	2326.0	12.9	33.2
High-Al weld	650 (1202°F)	80	296.4	42.6	59.8
Low-Al weld	650 (1202°F)	80	4713.6	13.5	36.1

Hardness Distributions

Figure 4A shows the transverse cross section of the high-Al weld in the as-welded condition. Due to the multipass nature of the weld, the microstructure in the fusion zone is not uniform. Figure 4B shows the hardness distribution in the weld, which is not uniform, either. The HAZ of a pass can be well inside the fusion zone and HAZ of its previous pass. This can cause local reheating and hence microstructural and hardness changes within the fusion zone (Refs. 9, 34).

As can be seen from the last pass shown in Fig. 4B, the maximum hardness is about 475 HV and is immediately along the fusion boundary, that is, the coarse-grained HAZ (CGHAZ). This is reasonably close to the average hardness of about 510 HV observed by Silwal et al. (Ref. 31) in the CGHAZ of P91 steel in the as-welded condition. According to them, the CGHAZ experienced during welding a peak temperature between 1100°C (above the A_{C3} temperature 925°C) and the melting temperature of 1382°C, thus allowing complete carbide dissolution and austenite grain growth and hence formation of brittle martensite upon cooling.

Figure 4C shows the transverse cross section of the low-Al weld in the as-welded condition. As compared to the high-Al weld (Fig. 4A), the low-Al weld has a more uniform microstructure due to the more and smaller passes used (33 vs. 13). The microhardness distribution in the fusion zone, as shown in Fig. 4D, is also more uniform than that of the high-Al weld (Fig. 4B).

Figure 5A shows the transverse cross section of the high-Al weld after PWHT at 760°C (1400°F) for 4 h. As compared to the as-welded condition (Fig. 4A), the microstructure in the fusion zone is more uniform. Consequently, the microhardness in the fusion zone is also more uniform as can be seen in Fig. 5B. On the average, the

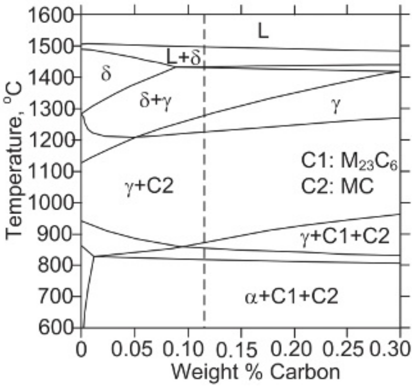


Fig. 8 — Quasi-binary phase diagram of T91 steel (Ref. 36) shown here to illustrate formation of δ-ferrite in fusion zone during solidification and in HAZ during reheating by subsequent passes to near 1300°C. Incomplete transformation of the δ-ferrite to austenite γ upon cooling causes retained δ-ferrite.

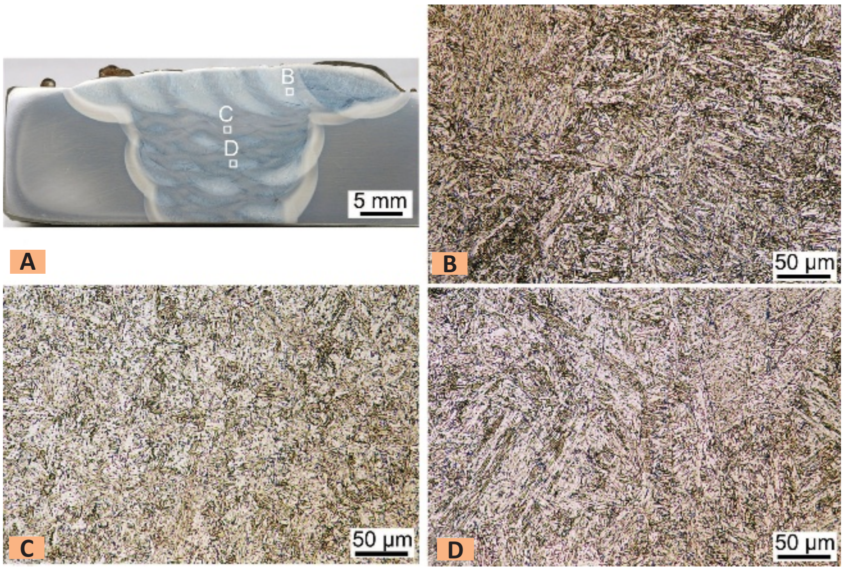


Fig. 9 — Absence of δ-ferrite in low-Al weld in as-welded condition. A —Transverse macrograph of weld; B — optical micrograph at point B in A; C — at point C; D — at point D.

Table 4 — Solubility Products[(a)] for Carbides and Nitrides in Steels (Ref. 40)

Compound	Metal	Nonmetal	A	B
$Cr_{23}C_6$	Cr	C	5.90	7375
V_4C_3	V	$C_{0.75}$	5.36	8000
TiC	Ti	C	2.75	7000
NbC	Nb	$C_{0.7}$	3.11	7520
Mo_2C	Mo	C	5.0	7375
Nb(C,N)	Nb	(CN)	2.26	6700
VN	V	N	2.27	7070
VN	V	N	3.46 + 0.12%Mn	8330
AlN	Al	N	1.80	7750
AlN	Al	N	1.03	6770
NbN	Nb	N	4.04	10230
NbN	Nb	N	3.70	10800
TiN	Ti	N	0.32	8000

(a) The data refer to dissolution of M_aC_b or M_aN_b. Following the equation $\log_{10}(C^a_M C^b_N) = A – B/T$ with concentrations measured in wt-% and T in K.

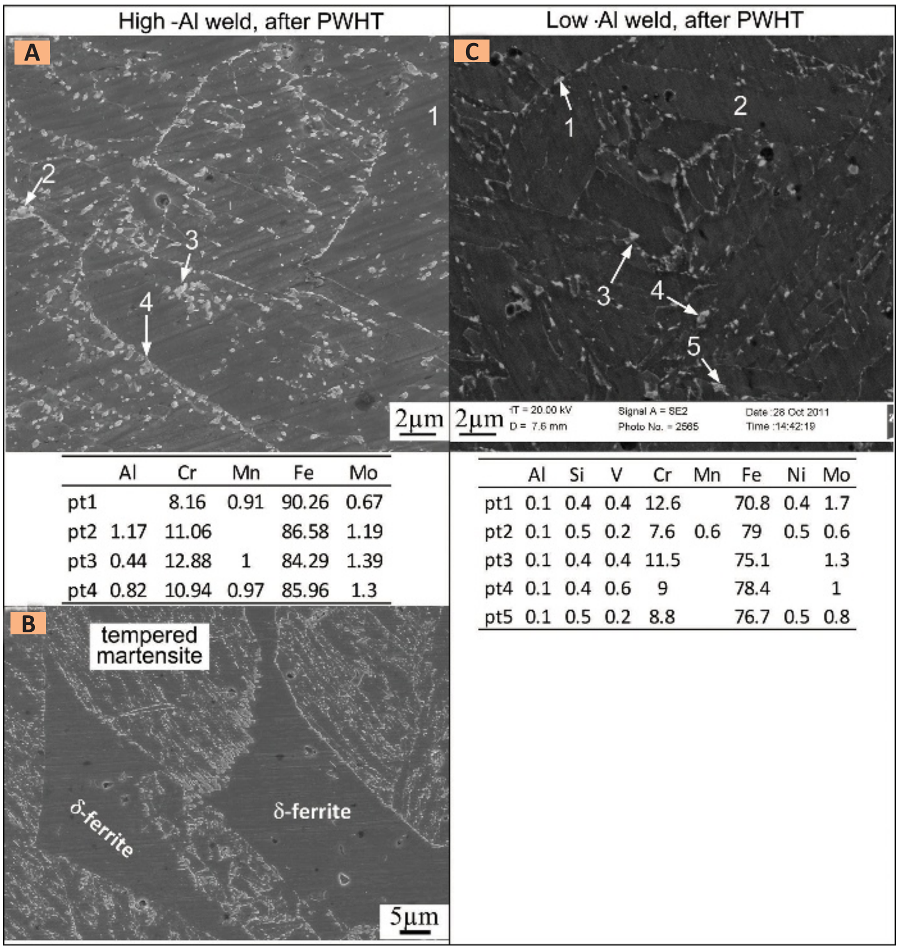
hardness is significantly lower after postweld heat treatment. For better resolution of the hardness distribution, a different color scale for hardness was used in Fig. 5C. As can be seen from the last pass shown in Fig. 5C, the maximum hardness is about 290 HV and is again in the CGHAZ immediately along the fusion boundary. The PWHT at 760°C for 4 h did not make the CGHAZ identical to the base metal in hardness, but it still reduced the CGHAZ hardness significantly (from about 475 to 290 HV). Silwal et al. (Ref. 31) reduced the hardness in the CGHAZ of P91 steel from about 510 to 290 HV after PWHT at 800°C for 2 h.

Figure 5D shows the transverse cross section of the low-Al weld after PWHT at 760°C (1400°F) for 4 h. The microstructure in the fusion zone is more uniform than that in the as-welded condition — Fig. 4C. The microhardness in the fusion zone is shown in Fig. 5E, which is also more uniform and, on the average, significantly lower than that in the as-welded condition — Fig. 4D. In Fig. 5F, a different color scale for hardness is used to show the hardness distribution.

In order to determine the average hardness in the fusion zone, additional microhardness measurements were conducted manually in the weld specimens after PWHT, and the results are shown in Fig. 6. For the high-Al weld, the average hardness in the fusion zone is 219 HV. This corresponds to an ultimate tensile strength (UTS) of 738 MPa (107 ksi) according to standard charts for converting hardness to UTS (Ref. 35). This UTS is very close to the UTS of 703 MPa (102 ksi) measured in the tensile testing of the high-Al weld specimen after PWHT. For the low-Al weld, the average hardness in the fusion zone is 247 HV, which corresponds to a UTS of 841 MPa (122 ksi) according to the conversion table. The room-temperature strength of the high-Al weld (738 MPa) is only somewhat (12%) lower than that of the low-Al weld (841 MPa). As suggested by one reviewer of the present study, Fig. 2 was replotted such that the applied stress was substituted by the ratio of the applied stress to the UTS. The two curves only moved slightly closer to each other instead of collapsing onto one. This new plot seems to suggest that the much lower creep resistance of the high-Al weld was not caused by its lower strength but by its less favorable microstructure (including its coarse precipitates).

Optical Microscopy and δ-Ferrite

The optical microstructure of the high-Al weld is shown in Fig. 7. The presence of δ-ferrite in the fusion zone



	Al	Cr	Mn	Fe	Mo
pt1		8.16	0.91	90.26	0.67
pt2	1.17	11.06		86.58	1.19
pt3	0.44	12.88	1	84.29	1.39
pt4	0.82	10.94	0.97	85.96	1.3

	Al	Si	V	Cr	Mn	Fe	Ni	Mo
pt1	0.1	0.4	0.4	12.6		70.8	0.4	1.7
pt2	0.1	0.5	0.2	7.6	0.6	79	0.5	0.6
pt3	0.1	0.4	0.4	11.5		75.1		1.3
pt4	0.1	0.4	0.6	9		78.4		1
pt5	0.1	0.5	0.2	8.8		76.7	0.5	0.8

Fig. 10 — Results of EDS composition analysis after postweld heat treatment. A — High-Al weld in area free of δ-ferrite; B — δ-ferrite in high-Al weld showing no precipitates; C — low-Al weld. Cr contents are higher at precipitates 2, 3, 4 than matrix at point 1 in A and at precipitates 1 and 3 than matrix at point 2 in C, suggesting the precipitates are likely to be $M_{23}C_6$.

is evident. A polygonal, light-etching phase distinctly different from the surrounding martensite matrix can be seen in the HAZ of the second to last pass (Fig. 7B) and the HAZ of the last pass (Fig. 7C). This phase is expected to be δ-ferrite, judging from its significantly lower hardness than the surrounding matrix. Although the weld metal can be reheated into the δ + γ region of the phase diagram during multipass welding, the presence of δ-ferrite is not likely to be caused by this reheating. First, reheating also occurred in the low-Al weld made by multipass SMAW but, as is shown subsequently, no δ-ferrite was found. Second, δ-ferrite was found in the fusion zone of the last pass of the high-Al weld (Fig. 7D), which was not reheated by any passes.

The presence of δ-ferrite suggests it did not transform completely to austenite during cooling. For the purpose of discussion, the quasi-binary phase diagram calculated for T91 steel (reasonably close to P91 steel) by Ayala et al. (Ref. 36) using *Thermo-Calc* is shown in Fig. 8. The carbon contents of the high- and low-Al welds are 0.114 and 0.117 wt-%, respectively (Table 2). As shown, the weld pool solidifies with δ-ferrite as the primary solidification phase. δ-ferrite transform to austenite γ, which can in turn transform to martensite upon further cooling. However, using in-situ X-ray diffraction by synchrotron radiation, Mayr et al. (Ref. 23) showed that the δ → γ transformation in a 9-Cr steel similar to P91 steel is incomplete. With a simulated thermal cycle like in welding, the steel was heated to a peak temperature of 1300°C in the δ + γ region and cooled to the room temperature. The transformation of δ-ferrite into austenite during cooling was incomplete. About 2% retained δ-ferrite was found in a matrix of martensite.

According to Paul et al. (Ref. 37), the Cr equivalent Cr_{eq} can be written as follows for welds of P91 steel:

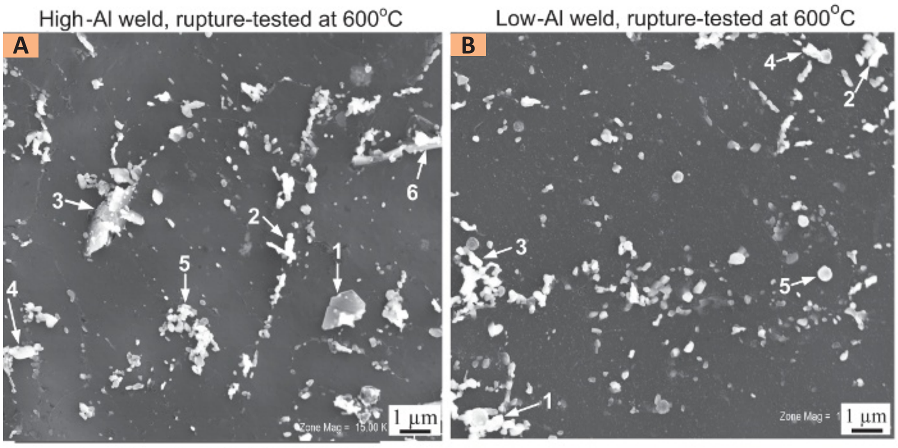
$$\begin{aligned} Cr_{eq} &= Cr + 6Si + 4Mo + 1.5W \\ &+ 11V + 5Nb + 12Al + 8Ti - 40C \\ &- 2Mn - 4Ni - 2Co - 30N - Cu \end{aligned} \tag{2}$$

where the elements are expressed in wt-%, e.g., 8.09 for Cr, whose content in the high-Al weld is 8.09 wt-%. The plus signs are for elements that are ferrite stabilizers, and the minus signs for those that are austenite stabilizers. As shown, Al is a stronger ferrite stabilizer, 12 times stronger than Cr.

Based on the composition of the high-Al weld shown in Table 2 and Equation 2, the Cr equivalent of the high-Al weld is 11.11. According to Paul et al. (Ref. 37), if the Cr equivalent of the P91 steel is greater than 9, δ-ferrite can exist. This seems to be consistent with the presence of δ-ferrite in the high-Al weld. As for the low-Al weld, the Cr equivalent is 8.25 based on its composition in Table 2 and Equation 2. This is consistent with the microstructure of the low-Al weld in Fig. 9, which shows no δ-ferrite in the matrix.

Electron Microscopy and Precipitates

Figure 10A shows a SEM image, along with the results of EDS composition analysis, of the high-Al weld after PWHT in an area away from δ-ferrite. Here precipitates are visible both along grain boundaries and inside grains. Point 1 represents a location in the matrix away from precipitates. It shows 8.16 wt-% Cr and 0.67 wt-% Mo. The precipitate near point 2 is richer in Cr than point 1, which suggests the precipitate is likely $M_{23}C_6$. Precipitates of $M_{23}C_6$ have been observed in P91 steels (Refs. 1–4). A similar difference has been reported previously. For instance, Panait et al. (Ref. 4) showed a higher Cr content in $M_{23}C_6$ precipitates than in the surrounding matrix. Figure 10B is a similar SEM image in an area with δ-


High-Al weld, rupture-tested at 600°C
Low-Al weld, rupture-tested at 600°C
A
B
1
2
3
4
5
6
1 µm
Zone Mag = 15.00 K
Zone Mag =

	Al	Si	V	Cr	Mn	Fe	Mo
pt1	74.4	10.2		4		3.4	
pt2	3.5	0.5	0.9	47.5	1.4	24.5	6
pt3	51	1.5		2.3		1	1.8
pt4	0.7	0.8	0.7	44.4	1.3	23.5	5.8
pt5	1.1	1.1	0.9	48.1	1.4	23.3	7
pt6	39.7	5.7	0.8	26.4		13.2	7.3

	Si	Ti	V	Cr	Mn	Fe	Ni	Nb	Mo
pt1	33.2	2.2	3.7	19.7	17.3	9.3		2.6	10
pt2	4.3		1.1	11.5	0.9	43.9	1.1		36.5
pt3	1.6		1.4	53.2	1.2	28	1.1		13.1
pt4	5.2	1.8	3.9	46	10.7	19.3	0.4	2	9.3
pt5	29.2	1.5	11.8	7	43.2			2.9	

Fig. 11 — SEM images of carbon replicas from transverse cross sections near fracture surfaces of creep specimens tested at 600°C. A —High-Al weld showing coarser precipitates containing Al (points 1, 3); B — low-Al weld showing no such precipitates.

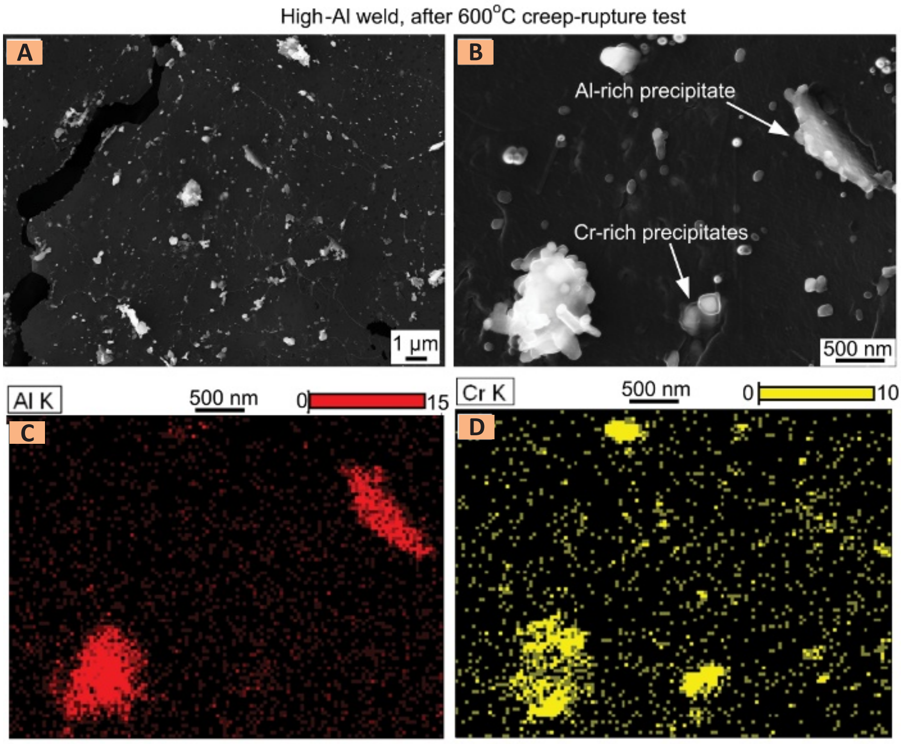


Fig. 12 — Carbon replica from transverse cross section near fracture surface of high-Al weld specimen after 600°C creep rupture test. A — SEM image; B — enlarged SEM image; C — Al distribution in Fig. 12B suggesting presence of coarse Al-rich precipitates; D — Cr distribution in Fig. 12B suggesting presence of Cr-rich $M_{23}C_6$ precipitates.

ferrite. As shown, δ-ferrite is precipitation free, which makes it soft. Figure 10C shows a SEM image of the low-Al weld after PWHT along with the results of EDS composition analysis. The higher Cr contents of the precipitates near points 1 and 3 than that at point 2 in the matrix suggest that the precipitates are likely $M_{23}C_6$.

Figure 11A shows the SEM image of a carbon replica from the transverse cross section near the fracture surface of the high-Al weld specimen tested at 600°C (1112°F) and 155 MPa. It shows near points 1 and 3 plate-like precipitates that are considerably larger in size than $M_{23}C_6$. The EDS composition analysis shows these precipitates are Al-rich without detectable V. Figure 11B shows the SEM image of a carbon replica from the transverse cross section near the fracture surface of the low-Al weld specimen after creep rupture testing at 600°C and 155 MPa. As compared to the high-Al weld (Fig. 11A), the precipitates are smaller and more uniformly distributed. Furthermore, unlike in the high-Al weld, the precipitates here contain significantly more V and no detectable Al.

Figure 12 shows the element mapping of the transverse cross section near the fracture surface of the high-Al weld specimen tested at 600°C and 155 MPa. Two large precipitates about 1 µm in size are visible in Fig. 12B, the one in the upper-right corner being plate-like. Both are rich in Al as shown by the Al map in Fig. 12C. The Cr map in Fig. 12D shows two isolated Cr-rich precipitates and two others in the lower left corner that seem to be sitting on top of a large Al-rich precipitate that is presumably plate-like. The two large precipitates in Fig. 12B are further analyzed by transmission electron microscopy (TEM) in Fig. 13. Considering the small but significant N content in the fusion zone, the two large Al-rich precipitates are likely to be AlN. They can be seen in the TEM image in Fig. 13B. The large precipitate on the upper-right corner shows a diffraction pattern similar to that of AlN, as can be seen by comparing Fig. 13C with Fig. 13D.

Figure 14 shows the element mapping of the transverse cross section near the fracture surface of the low-Al weld specimen tested at 600°C and 155 MPa. Precipitates are shown by the SEM image in Fig. 14A, wherein some small precipitates about 100 nm in size are visible. The Cr-map in Fig. 14B suggests these precipitates are $M_{23}C_6$. However,

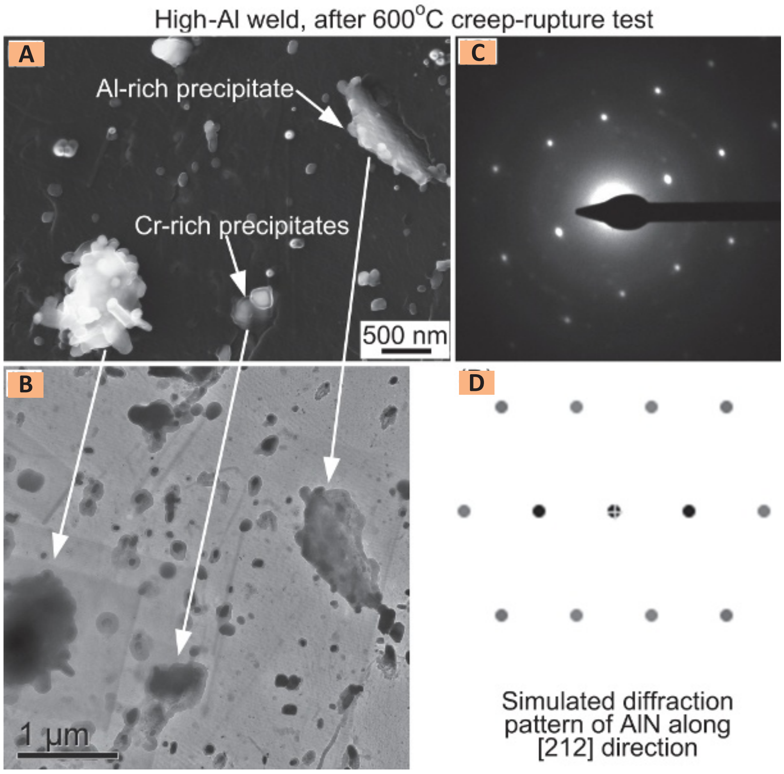

High-Al weld, after 600°C creep-rupture test
A
Al-rich precipitate
Cr-rich precipitates
500 nm
C
B
1 μm
D
Simulated diffraction pattern of AlN along [212] direction

Fig. 13 — Evidence of AlN precipitates in high-Al weld specimen after 600°C creep rupture test: A — SEM image of carbon replica (same as Fig. 12B); B — TEM image at same location as in Fig. 13A; C — electron diffraction pattern of the Al-rich precipitate in Fig. 13A; D — simulated diffraction pattern of AlN indicating the Al-rich precipitate is AlN.

Table 5 — Supersaturation Temperature of Nitrides in High-Al Weld

Compound	A	B	Supersaturation Temperature (°C)
VN	2.27	7070	1257
VN	3.46 + 0.12%Mn	8330	1175
AlN	1.80	7750	1477
AlN	1.03	6770	>1500
NbN	4.04	10230	1087
NbN	3.70	10800	1231

Table 6 — Supersaturation Temperature of Nitrides in Low-Al Weld

Compound	A	B	Supersaturation Temperature (°C)
VN	2.27	7070	1257
VN	3.46 + 0.12%Mn	8330	1319
AlN	1.80	7750	<800
AlN	1.03	6770	<800
NbN	4.04	10230	1101
NbN	3.70	10800	1247

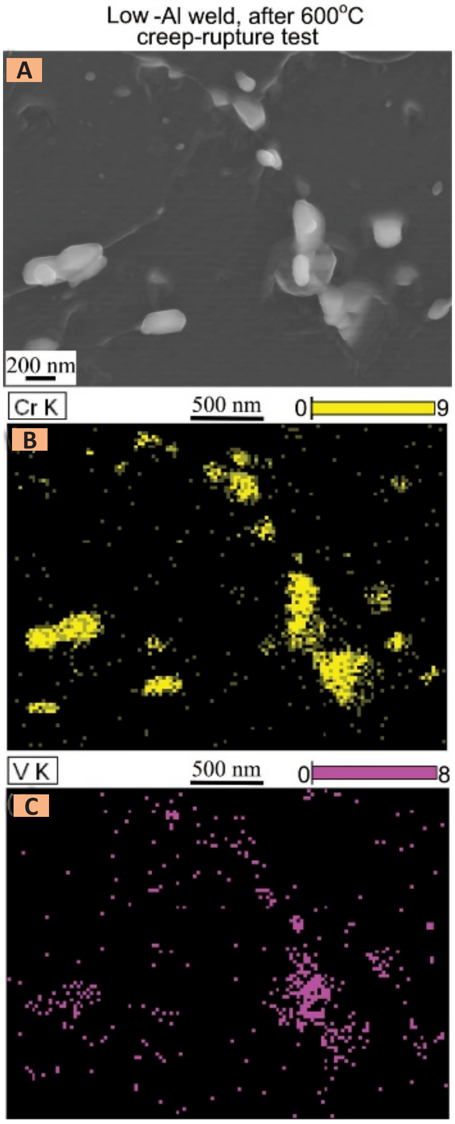


Fig. 14 — Evidence of V(CN) precipitates in low-Al weld specimen after 600°C creep rupture test. A — SEM image of carbon replica from transverse cross section near fracture surface; B — Cr distribution suggesting presence of Cr-rich $M_{23}C_6$ precipitates; C — V distribution suggesting presence of V(CN) precipitates.

the coexistence of more than one type of precipitate seems visible at some locations in the SEM image Fig. 14A. The V-map in Fig. 14C suggests the presence of V-containing precipitates and their coexistence with the larger $M_{23}C_6$ precipitates. These V-containing precipitates are likely to be V(CN).

Thermodynamic and Kinetic Analyses

A thermodynamic analysis of nitride precipitates can be made based on the Ellingham diagram of nitrides shown in Fig. 15A (Ref. 38) for the relative stability of AlN, VN, and NbN. Since a nitride with a lower free energy of formation has a greater tendency to form, the diagram shows a greater tendency for AlN to form than either VN or NbN. This is consistent with the presence of AlN precipitates in the high-Al weld. However, the Ellingham diagram shows the standard-state condition and does not consider the actual concentrations of Al, V, Nb, and N in the welds.

A kinetic analysis of nitride precipi-

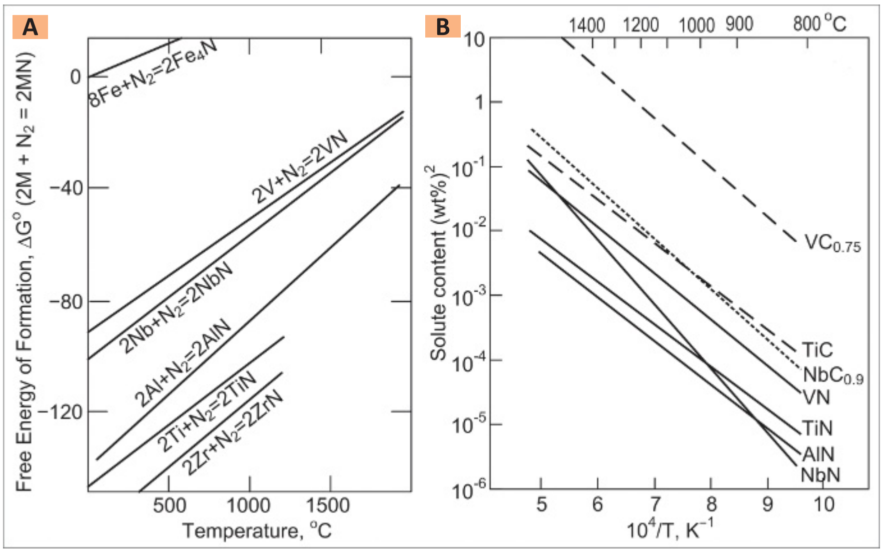


Fig. 15 — Effect of temperature on formation of nitrides. A — Ellingham diagram showing a greater tendency for AlN to form than VN and NbN under standard state (Ref. 38); B — solubility products of some nitrides and carbides in austenite (Ref. 39).

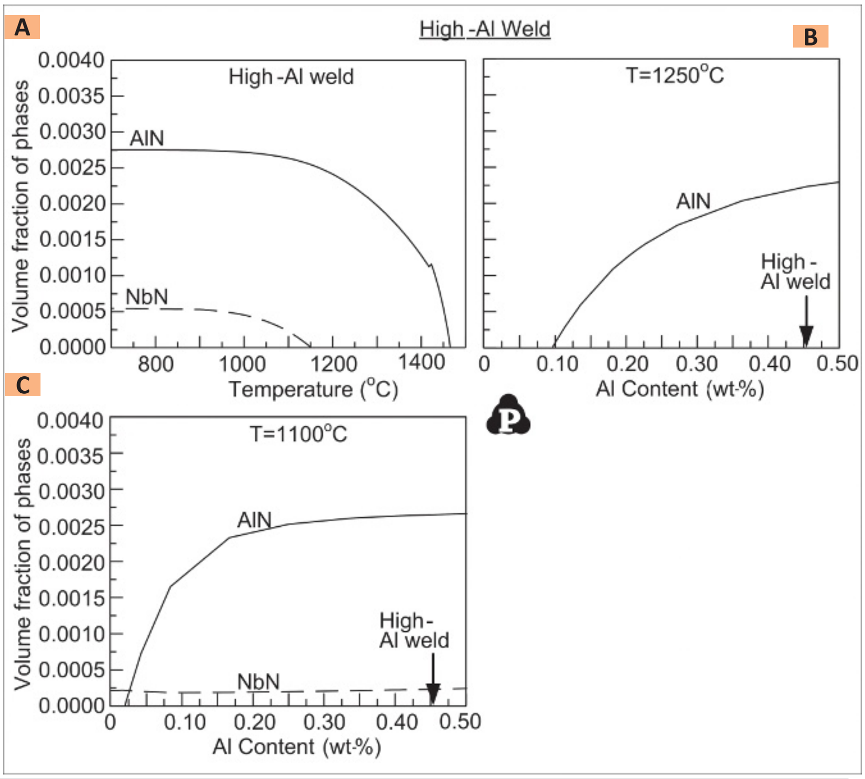


Fig. 16 — Dominance of AlN over NbN (and VN, which does not even form) in high-Al weld (0.455 wt-% Al). A — Volume fractions of nitrides vs. temperature; B — volume fractions of nitrides vs. Al content at 1250°C (with Al replacing Fe while contents of other alloy elements being kept identical to Table 2); C — volume fractions of nitrides vs. Al content at 1100°C. All curves calculated using Pandat *(Ref. 42) and* PanIron *(Ref. 43) of CompuTherm.*

tates can be made based on the solubility products of nitrides. Figure 15B shows the solubility products of nitrides (and some carbides) in steel according to Aronsson (Ref. 39). The solubility products of all the nitrides decrease as the temperature decreases. AlN has the lowest solubility product at the temperature above 863°C ($10^4/1136$ K = 8.8 K^{-1}), indicating AlN is likely to precipitate first during cooling after solidification. For a metal M, the solubility product of its nitride MN can also be calculated using the following equation (Ref. 40):

$$\log_{10}(C_M C_N) = A - B/T \qquad (3)$$

where the concentration C is in wt-% and temperature T in degrees Kelvin. The constants A and B are given in Table 4 in two different sets of values according to Ashby and Easterling (Ref. 40).

For a MN nitride such as AlN, VN, and NbN, the level of supersaturation at a given temperature can be defined as follows:

$$\text{Level of supersaturation} = (\text{wt-\% of } M \text{ in weld}) \text{x} (\text{wt-\% of N in weld}) / (C_M C_N) \qquad (4)$$

where the wt-% of M in the weld and the wt-% of N in the weld are given in Table 2 (composition of welds). A precipitate is considered supersaturated when the ratio is greater than 1.0, and the higher the ratio is, the greater the tendency for the precipitate to form. Calculated results for the high-Al weld based on Equations 3 and 4 in Table 2 are summarized in Table 5. As shown, AlN can reach supersaturation upon cooling to 1477°C or even before 1500°C. However, NbN and VN cannot reach supersaturation until further cooling to lower temperatures: NbN to 1087° or 1231°C, and VN to 1175° or 1257°C. Consequently, during cooling AlN can precipitate before VN and NbN, and this is consistent with the fact that no V-rich precipitates were found in the high-Al weld. Thus, AlN precipitates could have formed at the expense of V(CN) and Nb(CN) precipitates. Therefore, the absence of creep-resistant V(CN) and Nb(CN) precipitates is consistent with the poor creep resistance of the high-Al weld. It is worth mentioning that AlN inclusions about 1 μm in size were found in FCAW deposits containing 1.70 wt-% Al and 0.064 wt-% N without V or Nb, and they exhibited a faceted morphology (Ref. 41).

Calculated results for the low-Al weld based on Equations 3 and 4 and

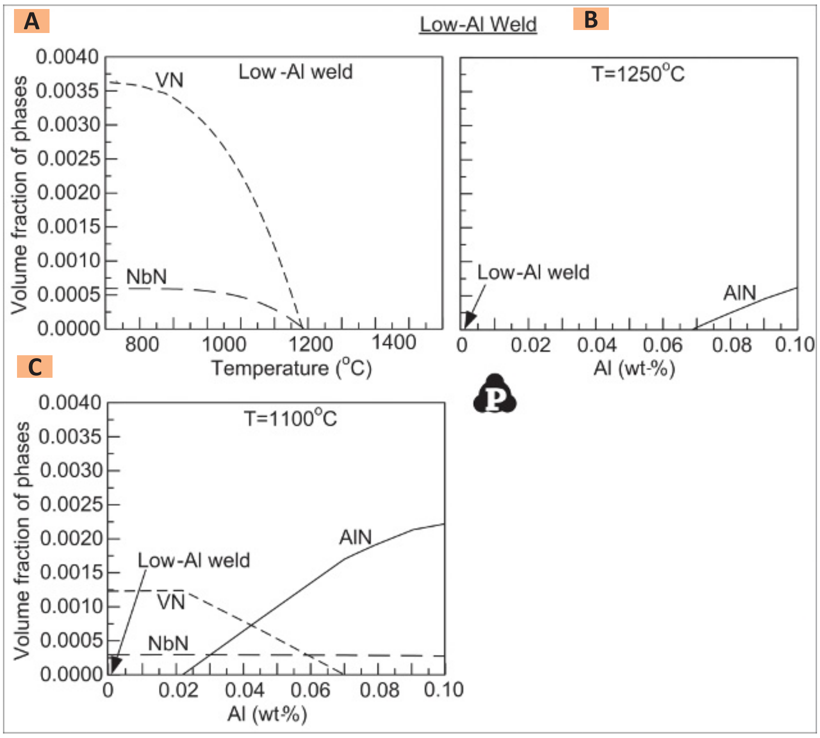


Fig. 17 — Dominance of VN and NbN over AlN in low-Al weld (0.001 wt-% Al). A — Volume fractions of nitrides vs. temperature; B — volume fractions of nitrides vs. Al content at 1250°C; C — volume fractions of nitrides vs. Al content at 1100°C. All curves calculated using Pandat *(Ref. 42) and* PanIron *(Ref. 43) of CompuTherm.*

Table 2 are summarized in Table 6. The lack of AlN in the low-Al weld is less due to the competition with other nitrides as the fact that there is almost no Al in the weld. Because of the very low Al content, AlN does not reach supersaturation upon cooling until below 800°C. However, NbN and VN can reach supersaturation upon cooling to higher temperatures: NbN to 1101° or 1247°C, and VN to 1257° or 1319°C. Consequently, during cooling VN and NbN can precipitate before AlN, and this is consistent with the fact that no Al-rich precipitates could be found in the low-Al weld.

In the study of Quintana et al. (Ref. 41) on Fe-C-Al-Mn steel welds made by FCAW, the thermodynamics computer software *ThermoCalc* was used to analyze the formation of AlN, Al_2O_3, and Ti(CN) precipitates in the welds.

In the present study, the thermodynamic computer software *Pandat* (Ref. 42) and the database *PanIron* (Ref. 43) of CompuTherm, LLC, were used to calculate the formation of nitride in the welds based on their compositions in Table 2. The calculated results for the high-Al weld are shown in Fig. 16.

Figure 16A shows that AlN precipitation starts at a much higher temperature than NbN formation and that no VN precipitates during cooling. Figure 16B and C showed volume fractions of nitrides vs. the Al content at 1250° and 1100°C, respectively. It shows that at 0.45 wt-% Al, precipitation of AlN dominates that of NbN and precipitation of VN does not even occur, consistent with the experimental results. It is perhaps worth mentioning that the solubility of nitrogen is much higher in δ-ferrite than in α-ferrite (Ref. 44). This may suggest that some N may be trapped in δ-ferrite in the case of the high-Al weld, thus further reducing the amount of N available for the precipitation of NbN and VN.

Similar results calculated for the low-Al weld are shown in Fig. 17. Figure 17C shows that at 0.001 wt-% Al, only VN and NbN can precipitate out but not the AlN, which is consistent with the experimental results. The lack of AlN in the low-Al weld is less due to the competition with other nitrides as the fact that there is almost no Al in the weld.

Conclusions

1) Stress rupture tests of welds of P91 steel made with significantly different Al contents in the fusion zones have shown that increasing the Al content can significantly reduce the creep resistance of P91 steel welds, from up to about 5000 h at 0.001 wt-% Al to up to about 300 h at 0.455 wt-% Al under the tested conditions in the present study.

2) Optical microscopy of the welds has shown that increasing the Al content can promote the formation of retained δ-ferrite in the matrix of tempered martensite, which is detrimental to the creep resistance of P91 steel. This effect of Al on the δ-ferrite formation is consistent with Al being a powerful ferrite stabilizer, twelve times more powerful than Cr according to Equation 2.

3) Electron microscopy and EDS composition analysis of the welds have shown that increasing the Al content can promote the formation of coarse (about 1 μm) AlN precipitates at the expense of the fine (< 100 nm) VN precipitates needed to resist creep.

4) Thermodynamic analysis based on the Ellingham diagram of nitrides suggests that AlN can have a greater tendency to precipitate than VN and NbN, at least under the standard state.

5) Kinetic analysis based on the solubility products of nitrides and the composition of the high-Al weld suggests that, during cooling after solidification, supersaturation can be reached to cause precipitation at a significantly higher temperature for AlN than for NbN and VN. Thus, AlN can be expected to precipitate first and use up N before NbN and VN can precipitate.

6) Computations using the computer software *Pandat* suggest that the dominance of AlN precipitation in the high Al-weld and the absence of AlN formation in the low-Al weld.

7) The presence of retained δ-ferrite and the absence of VN (or V(CN)) and NbN (or Nb(CN)) precipitates have contributed to the much lower creep resistance of the high-Al weld.

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Stability of the Cross-Arc Process — A Preliminary Study

A modified arc welding process is proposed to establish a cross-arc process where two wires are charged by a second power supply and fed into a traditional gas tungsten arc

BY S. J. CHEN, L. ZHANG, X. P. WANG, AND J. WANG

ABSTRACT

In traditional welding processes, the electrode is the cathode and the workpiece is the anode. In addition, their heat and mass inputs are coupled and unable to be freely optimized to suit the needs of specific applications. A modified arc welding process is proposed in this work to establish a cross-arc process where two wires are charged by a second power supply and fed into a traditional gas tungsten arc (GTA), which heats the workpiece. It is theorized an inter-wire arc can be established between the two wires to directly heat both wires, by which the heat and mass inputs are decoupled. Furthermore, because the wire is melted by the anode and cathode of the inter-wire arc, the wire melting efficiency is approximately tripled. To verify this idea, an experimental system has been established to experimentally demonstrate the feasibility of the proposed cross-arc welding process. To avoid the complexity introduced by metal transfer, the two wires are replaced by two carbon electrodes in this first preliminary study. There are two states of the cross-arc observed from experiments: stable and double arc. Experimental results confirmed that the stable cross-arc can be established and maintained. Analysis has been performed to discuss how the parameters affect the stability of the cross arc.

KEYWORDS

- Cross Arc • Gas Tungsten Arc Welding (GTAW) • Inter-Wire Arc
- Stability • Double Arc

Introduction

Gas tungsten arc welding (GTAW) is a widely used welding process. Since the arc is established between the nonconsumable tungsten electrode and workpiece, the arc is stable and easy to control to produce quality welds. Unfortunately, while it often requires adding filler metals, it lacks a desirable ability to melt filler metals at high speeds.

There are two commonly used approaches to adding filler metal in GTAW: cold-wire GTAW and hot-wire GTAW (Refs. 1–3). In cold-wire GTAW, filler metal is directly fed into the molten pool formed by the arc and melted by absorbing the heat from the molten pool. Hot-wire GTAW, as shown in Fig. 1, is similar to cold-wire GTAW, except that the wire is resistively heated before it merges into the molten pool. The final melting of the wire is finished by absorbing the heat from the molten pool. Hot-wire GTAW reduces the heat needed from the molten pool to melt the wire and thus improves the ability to melt the wire faster although the hot-wire GTAW becomes more complicated due to the need for an additional power supply to resistively heat the wire (Refs. 4–8).

Since the wire melting is finished by absorbing the heat from the molten pool during hot-wire GTAW, the wire deposition rate depends on the size of the molten pool, which in turn is approximately proportional to the arc energy. The deposition rate is thus proportional to the arc energy similarly as the cold-wire GTAW as shown in Fig. 2. This type of coupling is undesirable because it weakens the ability to control the heat input and deposition rate freely (Ref. 1).

Such undesirable coupling between the heat input and deposition rate also exists in conventional gas metal arc welding (GMAW), another type of widely used arc welding process. In fact, GMAW is normally used in direct current electrode positive polarity, and while the wire is primarily melted by the anode heat, a greater part of the arc heat (cathode heat) is directly applied to the workpiece. Hence, the greater deposition rate, the greater heat input. Since all conventional arc welding processes distribute the anode and cathode of the arc on their respective electrode and the workpiece, it is difficult to separate the heat input and

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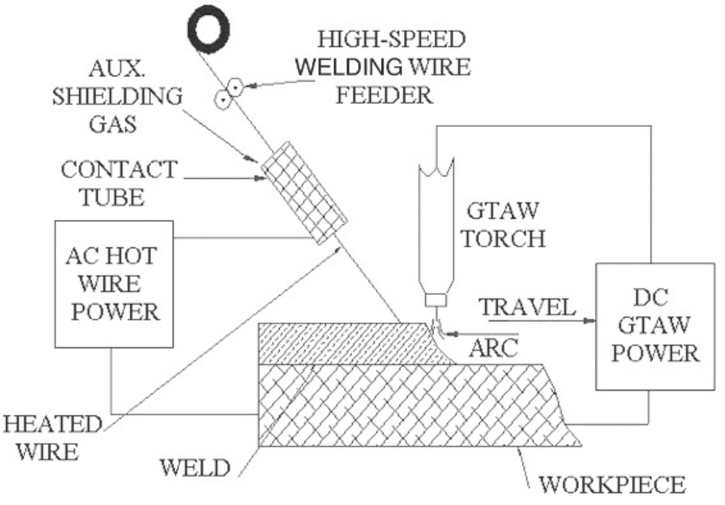

Fig. 1 — Hot-wire gas tungsten arc welding (Ref. 1).

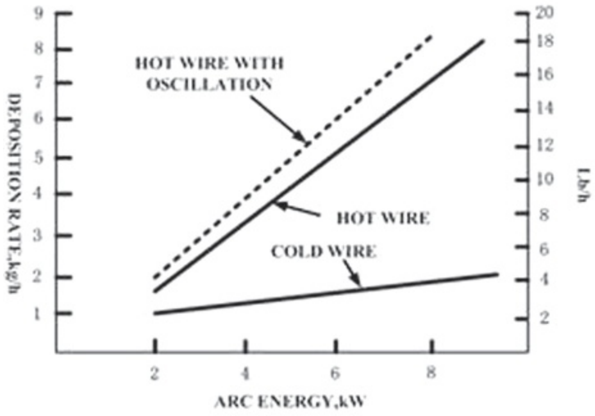

Fig. 2 — Deposition rates for GTAW with cold- and hot-steel welding wire (Ref. 1).

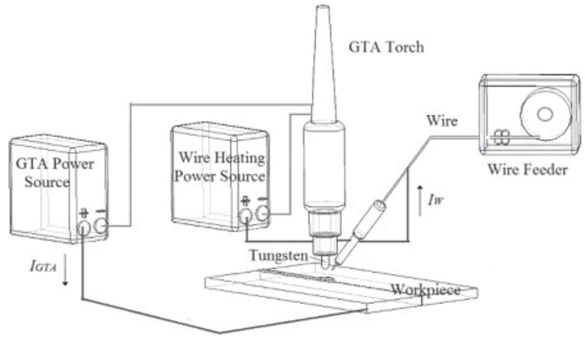

Fig. 3 — Arcing-wire GTAW system (Ref. 17).

deposition rate in traditional arc welding processes (Refs. 9, 10).

Double electrode gas metal arc welding (DE-GMAW) is a modified welding method with respect to traditional GMAW and it separately controls the heat input and deposition by adding a second electrode to bypass of the current, which otherwise would flow to the workpiece (Refs. 11–15). However, the base process is still GMAW. To increase the deposition rate and decouple the heat input and deposition rate, the arcing wire GTAW has been recently proposed as a modification to GTAW (Refs. 16, 17).

As shown in Fig. 3, a side arc is established between the tungsten and welding wire inside the GTA. The wire is melted without the need for heat from the molten pool and imposed additional heat in the workpiece. The deposition rate is increased, and the ability to provide a desirable deposition rate and base metal melting heat without coupling is established for GTAW, while the base process is still the stable GTAW. The current flowing through the tungsten is the sum of the two currents; the GTAW current controls the heat input and penetration of the workpiece, and the GMAW current determines the melting rate of the wire.

Although the arcing-wire GTAW significantly improves the deposition rate and decouples the heat input and deposition rate, the base process is still the stable GTAW. A small portion of the arc heat (cathode heat) is still wasted on the tungsten, and it adversely heats the tungsten electrode. The easy electron emission from the tungsten electrode minimizes this waste and adverse effect. Furthermore, this waste and adverse effect increases as the side arc current or the deposition rate increases (Refs. 16, 17). A further modification that can eliminate such waste and adverse effect is desired.

The Cross-Arc Process

The further modification this paper proposes is cross arc welding. As shown in Fig. 4, a gas tungsten arc (GTA) is established between the tungsten and workpiece as the main arc to heat the workpiece; the inter-wire arc is established between the two wires fed into the GTA to melt the two wires by its anode and cathode simultaneously. The inter-wire current for the inter-wire arc is provided by an AC power supply. The AC current waveform controls the melting speeds for any of the two wires. The inter-wire arc is under the GTA, and the GTA crosses each other with the inter-wire arc.

It can be seen from Fig. 4 that the heat from the GTA directly heats the workpiece and both spots (anode and cathode) of the inter-wire arc across the two wires melt the wires simultaneously. Since the arc column voltage is insignificant in comparison with the anode and cathode voltage, the efficiency of the cross arc in heating the filler metal approaches 100% while it is only 33% in conventional GMAW since the voltage drop of the cathode on the workpiece is approximately twice of the anode on the wire (Ref. 18). The deposition rate is tripled from that in conventional GMAW (Refs. 19–21). Moreover, the penetration and heat input on the workpiece can be controlled separately by the GTA and inter-wire arc; thus, a theoretically ideal modification is proposed.

Experimental System and Conditions

While using two wires provides a

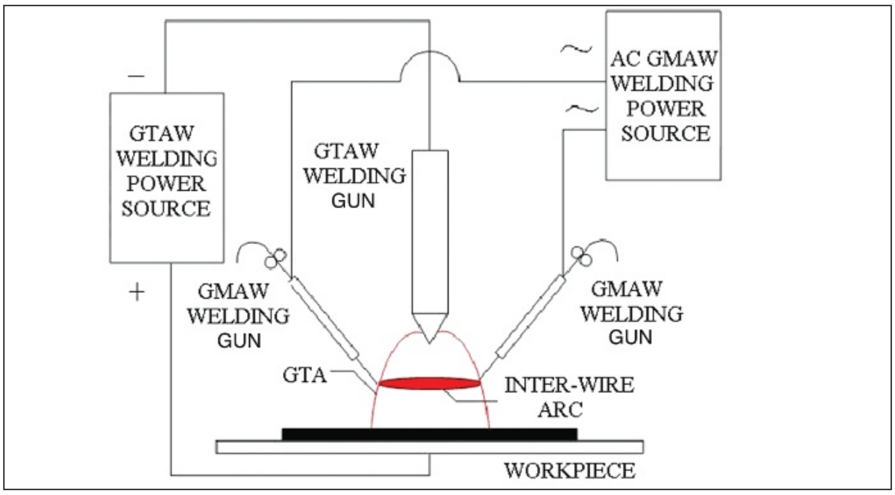

Fig. 4 — The proposed cross-arc welding process.

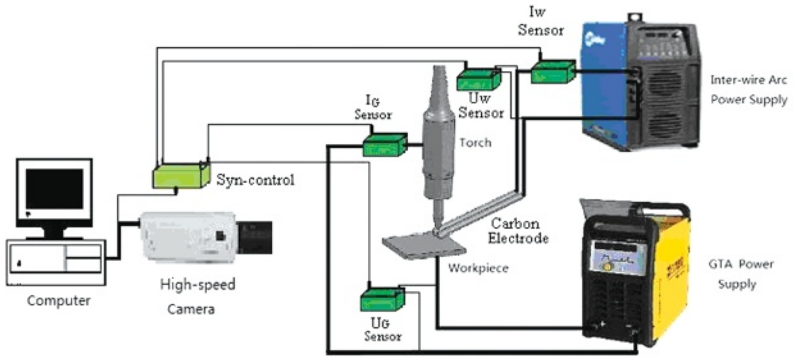

Fig. 5 — The cross-arc welding experimental system.

Table 1 — Cross-Arc Welding Experimental System Components

Equipment and Accessories	Model, Material, or Size
GTA power supply	Miller Dynasty 700
Inter-wire arc power supply	Time WSM-400
GTAW torch	Abicor and Binzel SR-26
Diameter of carbon electrode	Φ8 mm
High-speed camera	IDT motion Y4
Shielding gas of GTAW	Pure argon

way to melt the wire faster without imposing additional heat on the workpiece or tungsten, the operation of the proposed cross-arc welding relies on the balance between the melting of the two wires and sustaining of the cross arc between the two wires. Sustaining the cross arc depends on the melting balance. This study tries to verify the feasibility of the proposed idea, first without the coupling from the melting balance. The wires are first replaced by two nonconsumable electrodes.

An experimental system shown in Fig. 5 is established to experimentally demonstrate the feasibility of cross-arc welding. Specifically, the two wires are replaced by two carbon electrodes in this work to verify the feasibility to establish an arc between the wires.

In this system, a GTA is established using a DC-CC (direct current-constant current) power supply and an inter-wire arc is established using an AC-CC (alternating current-constant current) power supply. The inter-wire arc frequency is 100 Hz. A high-speed camera (without optical filter) is used to record the arc at 3000 frames/s. High-speed camera and arc signals were synchronized to observe the behaviors of the cross-arc process. The recorded current and voltage waveforms (at the sampling rate 150 kHz per channel) and images were used to judge the stability of the cross arc and determine the stability. The details for the experimental system are given in Table 1.

There are four parameters having a significant impact on the stability of the cross arc. The parameters that determine the stability of the cross are apparently include the inter-wire distance (between the carbon electrodes – D_W), wires elevation (from the workpiece to the carbon electrodes – D_H), GTA current (I_G), and inter-wire arc current (I_W). They are considered the major parameters affecting the stability of the cross arc in this study and are used to form the parameter vectors $\{D_W, D_H, I_G, I_W\}$. Each of them is assigned two or three values forming possible values for the parameter vector {(2 mm, 5 mm), (5 mm, 8 mm), (50 A, 100 A, 150 A), (50 A, 100 A, 150 A)}.

Additional parameters affecting stability include distance from the tungsten to the wire/carbon electrode, angle, and distance of the carbon electrode ends to the tungsten axis. They are, respectively, fixed at 5 mm, 10 deg, and 0 in this feasibility study; also, they are not subject to optimization.

The experimental results are listed in the table together with the corresponding parameters. Stable implies that the desirable state (stable arc) can be successfully established and maintained, while extinguished means the arc system is not maintained, and double arc refers to the undesirable double arc as aforementioned. Figure 6 uses images to compare the desirable state the double arc.

Figure 6A shows the normal or desirable state where the GTA and inter-wire arc cross each other. This is an ideal process as proposed because the heat input directly imposed on the workpiece is determined by GTA while the deposition rate is decided by the inter-wire arc. The ideal crossing of the two arcs makes the deposition rate and workpiece heat input/penetrated separately controllable.

Figure 6B shows an abnormal state where GTA is established between the

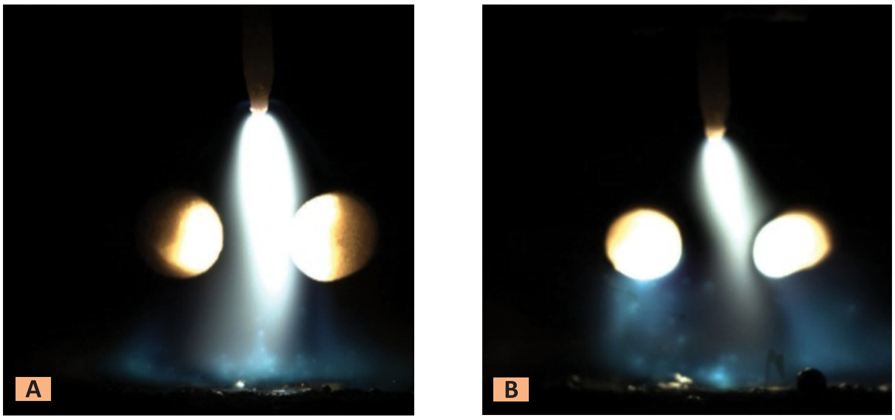

Fig. 6 — A — Stable arc; B — double arc.

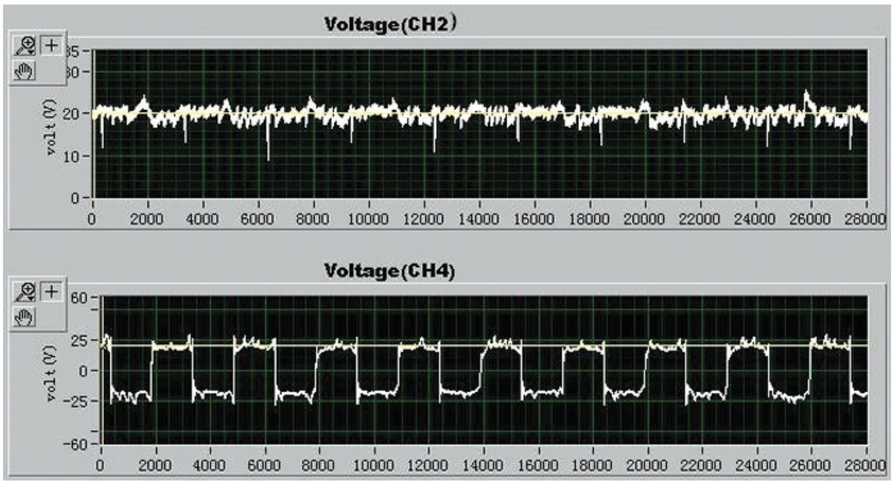

Fig. 7 — Voltage waveforms in experiment 1.

Table 2 — Cross-Arc Experimental Parameters

Group	Experiment	D_W (mm)	D_H (mm)	I_G (A)	I_W (A)	State
1	1	2	5	50	50	Stable
	2	2	5	100	50	Stable
	3	2	5	150	50	Stable
	4	2	5	50	100	Stable
	5	2	5	100	100	Stable
	6	2	5	50	150	Extinguished
	7	2	5	100	150	Double Arc
2	8	5	5	50	50	Double Arc
	9	5	5	100	100	Double Arc
	10	5	8	50	50	Double Arc
	11	5	8	100	100	Double Arc

tungsten and workpiece as desired, but the inter-wire arc is not established between the two carbon electrodes. It is seen that each carbon electrode pairs an arc with the workpiece. This is the double arc phenomenon. It is apparent that the double arc introduces two additional arcs to heat the workpiece. While the resultant double arc system may possess certain characteristics and deserve further exploration, it is not the cross-arc process proposed and is not discussed further in this paper.

Table 2 gives the parameters used to conduct the experiments. The resultant state — stable, extinguished, or double arc — is also listed and can be determined by the arc voltages, as will be discussed when presenting experimental results.

The experiments listed are divided into two groups in Table 2. In group 1, from experiments 1 to 7, the inter-wire and carbon electrode elevation are 2 and 5 mm, respectively, while the currents vary. D_W is relatively small. In group 2, experiments 8 and 9, D_W and D_H are equal and both 5 mm. From experiments 10 to 12 in group 2, the D_H increased 3 mm accordingly to prevent the double arc, in which the inter-wire current flows through the workpiece from one wire to another.

One may immediately realize it was the increased inter-wire distance that caused the undesirable double arc state since an increased elevation of the carbon electrode above the workpiece has made the establishment of an arc from the carbon electrode to the workpiece more difficult. It should be pointed out that not all the parameter vectors are included in Table 2. Only those that are illustrative and representative will be discussed and analyzed.

For example, no parameter vectors are listed for the circumstance when the inter-wire distance D_W is greater than the elevation D_H. Those parameters vectors produce, or are expected to produce, unsuccessful experimental results. They are considered to have little chance to succeed and are eliminated from being listed in the table.

Experimental Results

Each experiment will be presented with welding voltage waveforms — CH2 for the GTA voltage waveform, and CH4 for the inter-wire arc voltage waveform. The waveforms will be used to analyze the stability of cross-arc welding. There will also be a high-speed video consisting of 6 consecutive images for one cycle (a period of the AC inter-wire current waveform, which is 10 ms, was given earlier). The time interval between consecutive images is 5/3 ms, and it will be same for all the high-speed videos presented in this paper.

Group 1: Impact of I_G (GTA Current) and I_W (Inter-Wire Arc Current)

In group 1, experiments 1 to 7, the

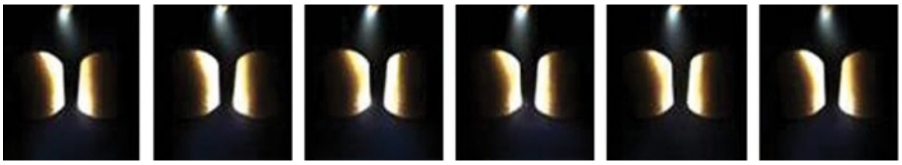

Fig. 8 — High-speed video of experiment 1.

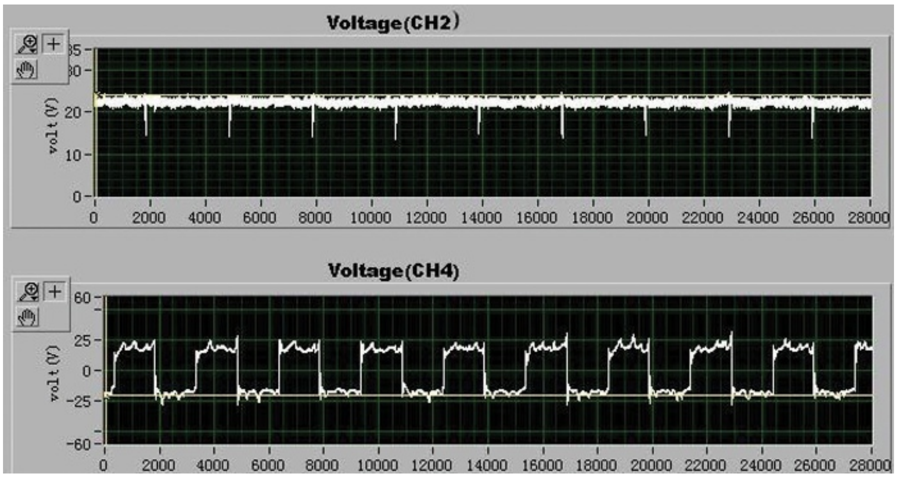

Fig. 9 — Voltage waveforms in experiment 2.

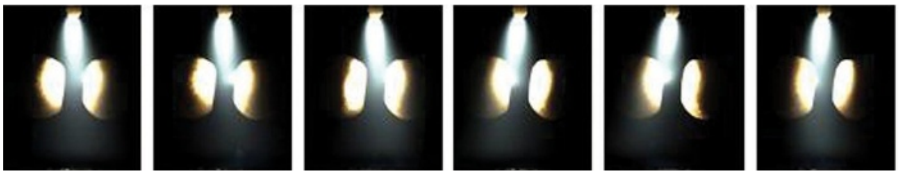

Fig. 10 — High-speed video of experiment 2.

distance of the inter-wire and carbon electrodes elevation are 2 and 5 mm, respectively. I_G is changed for each I_W to examine how I_G and I_W influence the cross-arc stability.

Experiments -1–3 {2, 5, (50, 100, 150), 50}

In experiments 1–3, the inter-wire current I_W is kept at 50 A and GTA current (I_G) is at the following three levels: 50, 100, and 150 A.

For experiment 1 with GTA current (I_G) at 50 A, the voltage waveforms are given in Fig. 7. The desirable stability of the inter-wire arc can be seen in its voltage waveform. In particular, the amplitude of the inter-wire voltage is approximately 20 V (CH4). This would suggest that there may be only one pair of arc spots (the cathode and anode). The undesirable double-arc phenomenon, which always accompanies with two pairs of arc spots, is ruled out. Further, the voltage is much lower than the open-circuit voltage. The two wires, actually the two replacing carbon electrodes, must be conducting through the arc such that the arc extinguishing condition can be ruled out. As such, the desired cross-wire arc has been established.

As can be further verified from the high-speed video in Fig. 8, there are no arcs between the carbon electrode and workpiece. The GTA voltage, which is approximately 20 V (CH2), suggests that there is only one pair of the arc spot between the tungsten and workpiece. Hence, the GTA and inter-wire arc are considered to cross each other. The feasibility of the proposed cross arc process is experimentally demonstrated.

Because of the relatively small amperage of the GTA and inter-wire arc currents, the arc plasma for both arcs is not always seen clearly in the high-speed video. However, it can still be observed that the GTA is not always straight. It may deviate either left or right from its straight trajectory. Analysis of the synchronized image, and cross arc voltage and current, showed that the GTA is straight when the cross arc is switching its polarity and the GTA deviates to the carbon electrode whichever is cathode.

In experiment 2, all the parameters are the same as in experiment 1 except for the GTA current, which has been increased from 50 to 100 A. The resultant voltage waveforms are given in Fig. 9. Again, from the voltage of the inter-wire arc, there are no double arcs. Since all the currents are nonzero, the arcs must have been established. The high-speed video is given in Fig. 10.

In experiment 3, the GTA current is further increased to 150 A. The voltage waveforms are given in Fig. 11. The inter-wire arc is stable, and the high-speed video is given in Fig. 12.

Experiments 4 and 5 {2, 5, (50, 100), 100}

To examine the effect of the inter-wire current, I_W increased from 50 A in experiments 1–3 to 100 A in experiments 4 and 5 with the following two levels of GTA current: 50 and 100 A. Their voltage waveforms and high-speed videos are given in Figs. 13–16. Again, stable inter-wire arcs are produced.

Experiments 6 and 7 {2, 5, (50, 100), 150}

When the inter-wire current (I_G) further increased to 150 A in experiments 6 and 7, the stable inter-wire arcs are no longer produced. While the arc is extinguished in experiment #6 for I_G at 50 A, the double arc occurs in experiment 7 with I_G at 100 A. The double arc phenomenon occurring in experiment 7 with I_G at 100 A can be clearly seen from the voltage waveforms and high-speed video shown in Figs. 17 and 18.

Group 2: Impact of D_W (Inter-Wire Distance) and D_H (Wires Elevation)

To examine how D_H and D_W impact stability of the cross arc, the inter-wire distance (D_W) is first increased to 5 mm to confirm whether the chance the double arc would be increased. The wire elevation (D_H) is increased the same to 8 mm to confirm that an increase in D_W may be compensated by a same increase in D_H in the second group of experiments.

Experiments 8 and 9 {5, 5, 50, 50} and {5, 5, 100, 100}

To examine the effect of the inter-wire distance (D_W), it increased from 2 to 5 mm in experiments 8 and 9 without changing D_H. The GTA current (I_G) and inter-wire arc current (I_W) are both 50 A in experiment 8 and 100 A in experiment 9 to compare with experiments 1 and 5, in which the stable cross arc has both been established, respectively.

The voltage waveforms and high-speed videos are shown in Figs. 19–22. As can be seen from the figures, the double arc has occurred in both experiments where D_W increased to 5 mm.

Experiments 10 and 11 {5, 8, 50, 50} and {5, 8, 100, 100}

Since the double arc has been caused by increasing D_W by 3 mm, the wire elevation (D_H) also increased 3 mm, from 5 to 8 mm, to see whether the effect due to the D_W increase can be compensated in experiments 10 and 11. Voltage waveforms (Figs. 23 and 25) and high-speed videos (Figs. 24 and 26) show that the double arc still occurs. The effect caused by inter-wire distance increase is not eliminated by the same increase in the wire elevation.

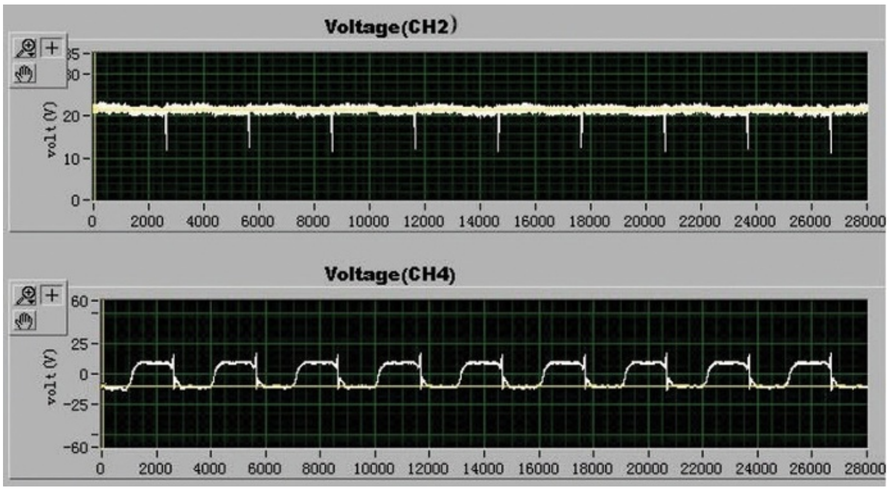

Fig. 11 — Voltage waveforms in experiment 3.

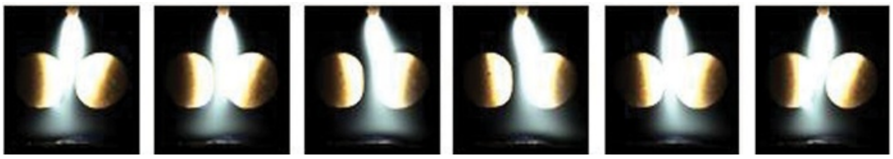

Fig. 12 — High-speed video of experiment 3.

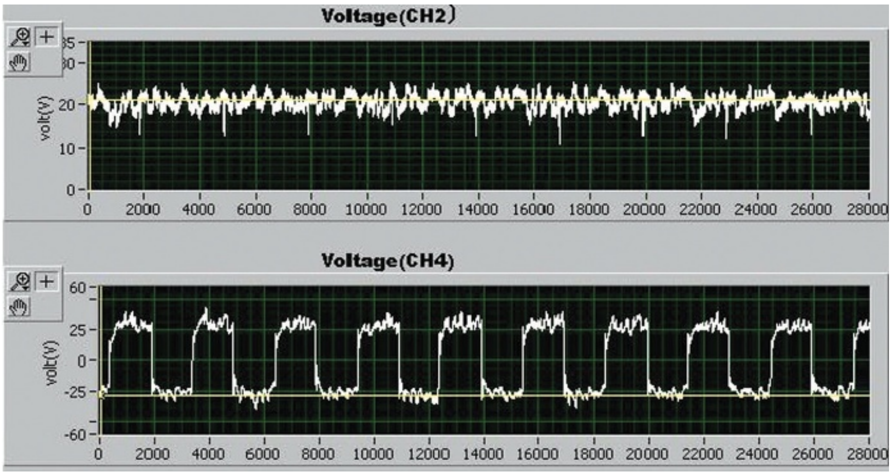

Fig. 13 — Voltage waveforms in experiment 4.

Analysis and Discussion

In cross-arc welding, a GTA and inter-wire arc are crossed. This is a unique arcing condition that does not exist in conventional arc welding processes. The GTA as the main arc exists between the tungsten and workpiece. The inter-wire arc is established between the two wires fed into the GTA and simultaneously heats its two terminals (anode and cathode) effectively.

While this mechanism facilities the heat input, and mass can be controlled separately, the arcing condition and phenomena are much more complex. Its feasibility must be experimentally demonstrated and verified. Then, the effects from different parameters on its arcing conditions and stability need to be understood.

Experimental Verification of Feasibility

Experiments 1–5 successfully demonstrated the feasibility of the proposed cross arcing mechanism. From the voltage waveforms recorded, the AC voltages between the two carbon electrodes in these experiments are all in the range of 20–25 V.

Experiments have been carried out to measure the voltage between the carbon electrodes. In such experiments, the GTA current and inter-wire current are not switched to zero during the arcing process. The voltage between the carbon electrodes is measured. The arcing process is also recorded using high-speed video to make

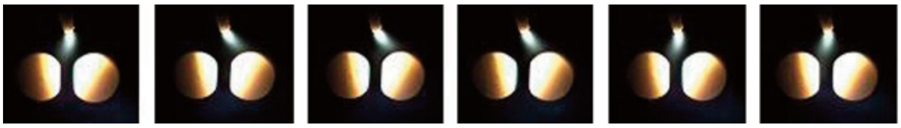

Fig. 14 — High-speed video of experiment 4.

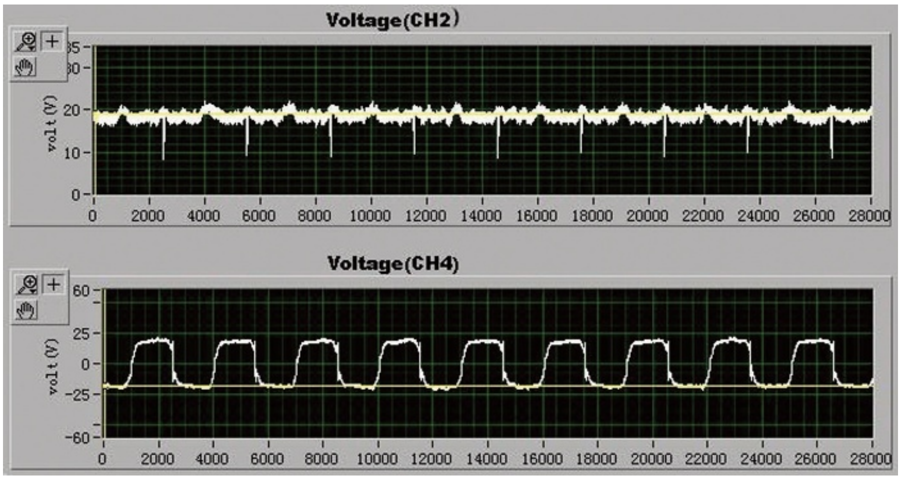

Fig. 15 — Voltage waveforms in experiment 5.

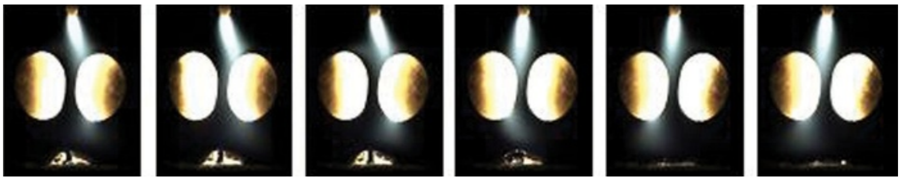

Fig. 16 — High-speed video of experiment 5.

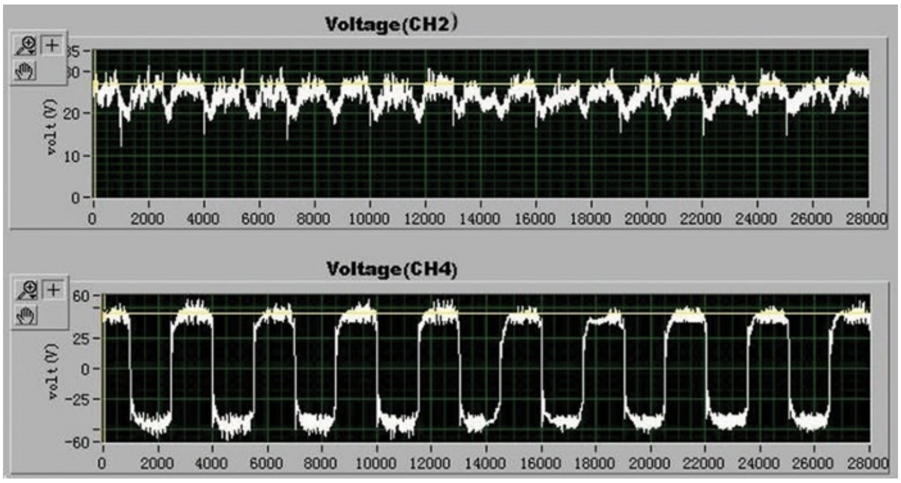

Fig. 17 — Voltage waveforms in experiment 7.

sure there is no double arc. The voltage record shows that the GTA voltage is approximately 20–25 V. Since there are no double arcs, the voltage recorded is the voltage of a single arc established between two carbon electrodes, which contain an anode and cathode pair. Since the distance between the two carbon electrodes is set to be approximately 2 mm, the column of the inter-wire arc is insignificant, and the sum of the anode and cathode voltage drops for the inter-wire arc should be slightly lower and in the range of approximately 18–23 V.

As such, if the double arc occurs, the inter-wire arc voltage must be at least increased by 18 V. Hence, there is a significant jump in the inter-wire arc voltage from the desired cross arc to the undesirable double arc. As a result, the inter-wire arc voltage can be used as a reliable criterion to judge if the arc is in the desirable cross-arc state (< 25 V as the upper limit), undesirable double arc state (> 38 V = 20 V + 18 V as the lower limit) or in the extinguishing state (= open circuit voltage, which is 75 V for the power source used). From this criterion, and from the voltage records in experiments 1–5, the desirable cross arc state has always been maintained. The proposed cross arcing mechanism is experimentally verified.

The successful establishment of the desirable cross arc can also be verified from the high-speed video. In an ideal video with the desirable cross-arc state, the two arcs should be clearly seen. However, the GTA established between a tungsten tip (relatively thin) and the workpiece is more concentrated and should be, in general, brighter than the inter-wire arc established between two large carbon electrodes if the currents are the same. The relatively concentrated shield gas from the GTA torch and the already distributive gas (from the GTA torch) between the two carbon electrodes further increases the difference in their brightness. However, such analyses only apply for the GTA above the carbon electrodes. For the GTA below the carbon electrodes, it will spread on the workpiece.

In addition, the shield gas has become further distributed. Hence, while the GTA should be brighter above the carbon electrodes, it will be dimmer below the electrodes.

Depending on the contrast among the different segments/components of the cross arc and video recording parameters, some arc components may not necessarily be clearly seen in all the videos. In particular, the opening between the carbon electrodes narrows the GTA such that the GTA is typically much brighter than the inter-wire arc. The inter-wire arc is overlapped spatially with the GTA in the opening. Hence, the inter-wire arc is typically not clearly identifiable from the video. The absence of the inter-wire arc in the video does not mean that the inter-wire is absent. As such, the videos from experiments 1–5 can be understood.

In the video of experiment 1, the low part of the GTA is not clearly seen. However, the GTA must have been established because there are no other loops for the electrons from the tungsten to return through any of the electrodes except through the workpiece. Also, the inter-wire arc is not seen in the high-speed video. In such case, the video would not serve as a direct evidence for the existence of the inter-wire arc, and the voltage waveform must be used as proof.

The inter-wire arc is typically absent in the high-speed video during the stable cross-arc state. Hence, it is always the case that the inter-wire arc is much weaker in the high-speed video. However, if the undesirable double arc occurs, its two segments between each electrode and the workpiece will be off the neighborhood of the bright GTA and become visible in the high-speed video. The result will provide a direct indication for the undesirable double-arc state.

While the lower part of the GTA is absent in the high-speed video (Fig. 8), in experiment 1 where the GTA current is 50 A, it becomes clearly visible (Fig. 10) in experiment 2 where the GTA current increased from 50 to 100 A. In experiment 3, the GTA current has been further increased to 150 A, and the entire GTA is clearly seen in the high-speed video — Fig. 12.

The voltage waveforms and high-speed videos in Figs. 7–16 clearly verified the success in establishing a desirable cross arc state, that is to say, the two arcs are established and crossed each without an undesirable double-arc phenomenon. The feasibility of the proposed cross-arc mechanism is experimentally verified.

Understanding GTA Swing

Careful observation of the high-speed videos in experiments 1–5 shows that GTA swings periodically with the polarity change among the carbon electrodes. The GTA deviates to the cathode electrode. The cathode switches from one carbon electrode to another; the GTA switches accordingly.

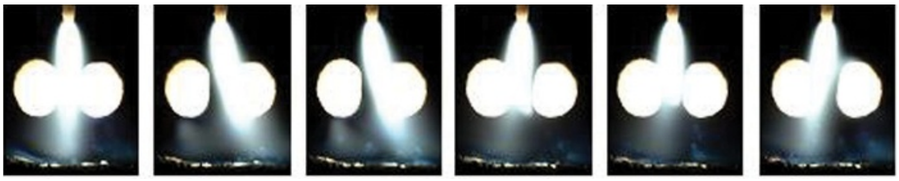

Fig. 18 — High-speed video of experiment 7.

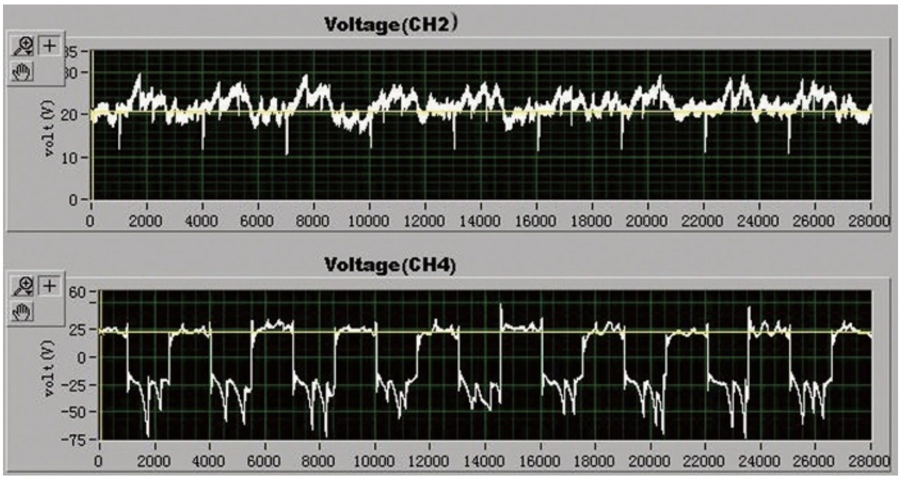

Fig. 19 — Voltage waveforms in experiment 8.

However, there is a small delay in the deviation after the polarity switch. This is perfectly understandable because the current polarity can be changed almost instantaneously, while the ionization of the gas and temperature rise in the gas to establish the arc in a new region requires time, although it is short. As can be seen in the videos, the GTA swing is apparent and can be easily identified from the videos.

The inter-wire current flowing from one carbon electrode to another generates a magnetic field in the GTA column. Figure 27 shows the directions of this magnetic field, i.e., inward and outward the paper above and below the carbon electrodes, respectively. In accordance with the left-hand rule (Ref. 22), the electrons from the tungsten electrode in such a magnetic field will be subject to an electromagnetic force, i.e., the Lorentz force, in the direction as shown in Fig. 27. That is, the force is toward the cathode of the electrodes. Hence, the GTA must deviate periodically as the polarity of the inter-wire current changes. This swing may provide a mechanism to scan the GTA on the workpiece.

As can be seen from the high-speed videos in the experiments using relatively large GTA current such that the lower part of the GTA is visible in the images, i.e., Fig. 12 for experiment 3 and Fig. 16 for experiment 5, the GTA does scan on the workpiece according to the polarity change. Therefore, the workpiece can be heated to better accept the metal deposit to form a relatively wide and shallow penetration. This is advantageous for applications where the deposition rate is concerned as the proposed process targets.

Effect from the Currents

While the cross-arc mechanism is feasible, successful establishment of the desirable cross arc depends on a number of parameters, including the currents for the GTA and inter-wire arc.

The GTA current (I_G) is an important parameter determining the stability of the cross arc because the inter-wire arc cannot be established without a GTA environment that can ionize the gas between the carbon electrodes. The stability of the GTA also affects

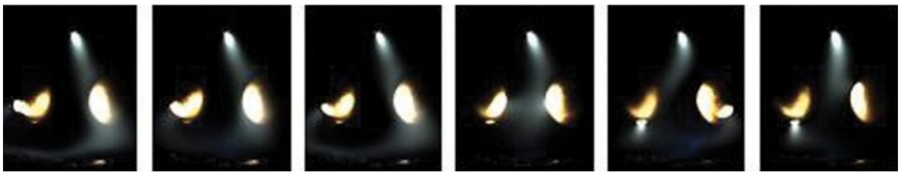

Fig. 20 — High-speed video of experiment 8.

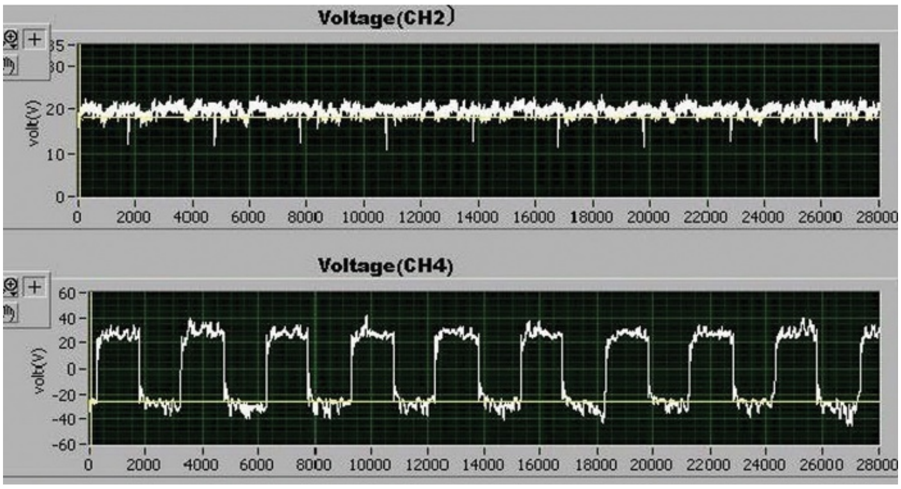

Fig. 21 — Voltage waveforms in experiment 9.

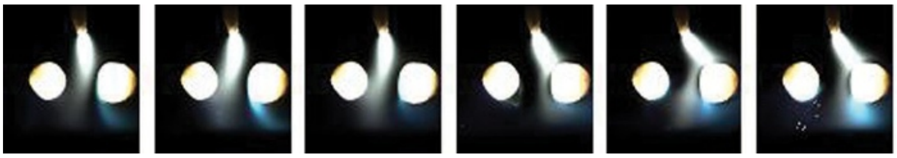

Fig. 22 — High-speed video of experiment 9.

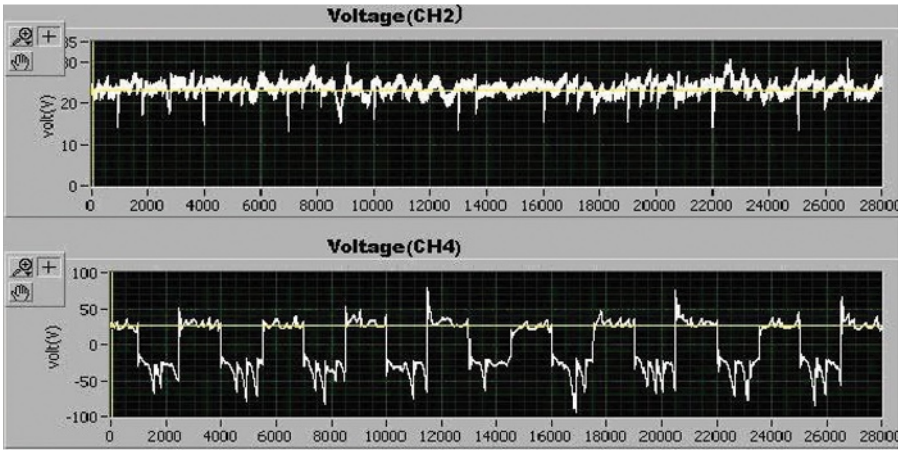

Fig. 23 — Voltage waveforms in experiment 10.

the stability of the conditions to establish the inter-wire arc. Furthermore, the stability of the GTA may also be affected by the inter-wire arc, thus the inter-wire current. Hence, it appears that the two currents both affect the stability of the cross arc system interactively.

In experiments 1–3, the GTA current (I_G) increases from 50 to 150 A while the inter-wire current is fixed at 50 A, which is not greater than the GTA current. In these experiments, the desirable cross-arc state has been successfully established and maintained. However, observation and comparison on the high-speed videos from the three experiments (Figs. 8, 10, and 12) clearly indicate that as the GTA current increases, the diameter of GTA increases, which leads to a better conductivity of the inter-wire opening and benefits the establishment and maintaining of the inter-wire arc.

Further, the swing is reduced as the GTA current increases. This is due to the improvement of the GTA stiffness, which increases with increasing the GTA current. A reduced swing in the GTA helps improve the ionization of the gas between the opening and stability of the inter-wire arc. Hence, an increase in the GTA current can improve conditions for the desirable cross arc.

The major effect of the inter-wire arc current (I_W) can be understood from its effect on the GTA swing. As has been analyzed using Fig. 27, the GTA is deviated by the electromagnetic force (Lorentz force) generated by the inter-wire arc current. Since the electromagnetic force increases, the swing increases as the inter-wire current increases when other parameters and conditions are unchanged. When the GTA is significantly deviated on an electrode, the electrons should flow into the electrode and then re-emit. In such a case, maintaining the GTA would require two pairs of arc spots, and the GTA may extinguish. As a result, as the polarity changes, the inter-wire arc would also extinguish. However, before such an extreme case occurs, increasing the inter-wire arc (arc current) may help ionize the gas to improve the GTA stability. Further, the swing of the GTA also depends on its stiffness, which improves with a higher GTA current. Hence, the effect of the inter-wire current on the GTA is coupled with the GTA current. The effect of the inter-wire arc current is relatively complex.

In experiment 4, the inter-wire current increased from 50 A in experiment 1 to 100 A, while the other parameters and conditions are unchanged. The arc is still stable. That is to say, the GTA is not extinguished by the increased inter-wire current. One can regard that the extreme conditions in which the GTA requires two pairs of

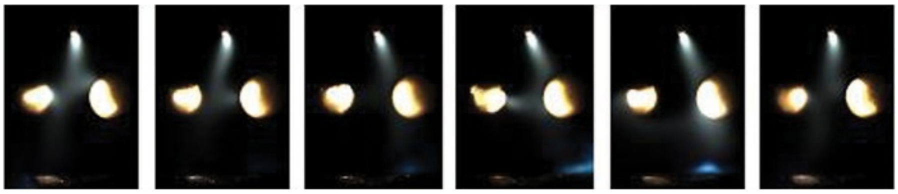

Fig. 24 — *High-speed video of experiment 10.*

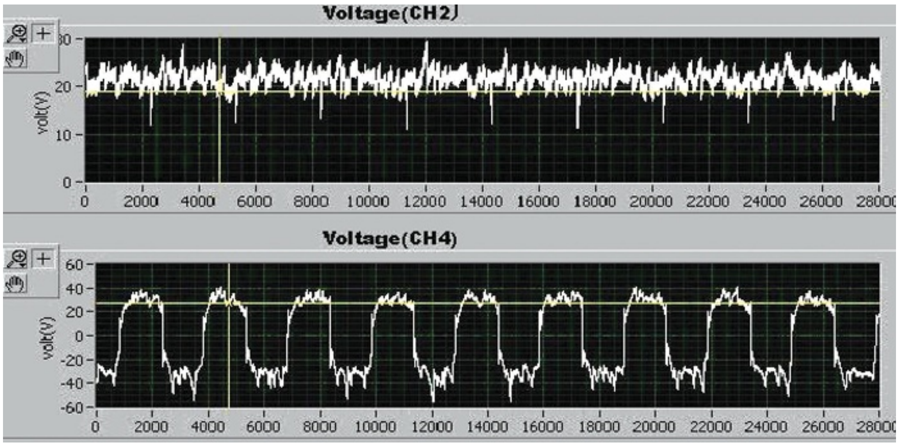

Fig. 25 — *Voltage waveforms in experiment 11.*

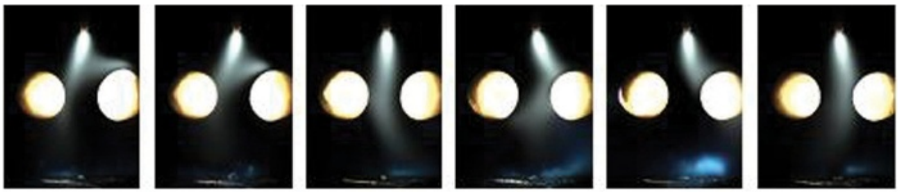

Fig. 26 — *High-speed video of experiment 11.*

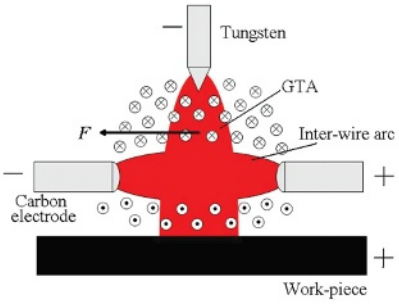

Fig. 27 — *The Lorentz force in a cross arc.*

arc spots has not occurred.

In experiment 4, the inter-wire current remains at 100 A. The conditions should be better to prevent the GTA from being extinguished because it becomes stiffer such that the deviation is reduced. Hence, the desirable cross arc state is also maintained in experiment 5.

However, when the inter-wire current increases to 150 A in experiment 6 while the GTA current still remains at 50 A, the arc extinguished. The authors believe that the much increased inter-wire current should have caused the occurrence of the aforementioned extreme conditions so that the need for two pairs of arc spots to maintain the GTA become necessary.

When the GTA current increases from 50 A in experiment 6 to 100 A in experiment 7, the double arc phenomenon occurs rather than arc extinguishing. The increased stiffness of the GTA can prevent the extreme deviation of the GTA. However, in such case, the inter-wire current is relatively large and the inter-wire arc diameter increases. The inter-wire column reduces its distance with the workpiece and may help to establish the conditions for double arc.

Effect from the Inter-Wire Arc Distance

It is apparent that a small inter-wire distance reduces the arc length of the inter-wire and improves the inter-wire arc stability as well as the cross-arc system.

In experiments 8 and 9, the inter-wire distance (D_W) increased from 2 mm in experiments 1 and 5, where the desirable cross-arc state has been successfully established and maintained, to 5 mm while other parameters and conditions are nominally unchanged. As can be seen from Table 2, as well as in Figs. 19–21, this increase in the inter-wire distance has caused the desirable cross arc to become an undesirable double arc, because the arc length of the inter-wire arc has been increased. An increased arc length will tend to increase the maximum of the arc column so that the inter-wire becomes closer to the workpiece. Furthermore, the crossed GTA will also tend to bend the inter-wire arc. The length of the arc to be bent increases, the deviation of its arc column also increases. As a result, an increased inter-wire distance tends to deviate the inter-wire arc toward the workpiece. The double arc would be easier to occur.

The increased inter-wire arc length due to an increase in the increased inter-wire distance also increases the length of the arc column to be affected by the GTA. As a result, the inter-wire arc would become less stable. As can be seen in Fig. 19 for the voltage waveforms in experiment 8, the inter-wire arc voltage fluctuates significantly. This voltage sometime becomes close to the open-circuit voltage (75 V). A greater inter-wire distance does not benefit the stability of the cross-arc system, especially when the inter-wire arc current is small, since a small current itself typically reduces the arc stability in conventional arc processes.

Effect from the Electrode Elevation

One may expect that a greater electrode elevation should help prevent the occurrence of the double arc. However, the significance of its effectiveness needs to be experimentally verified. Unfortunately, despite the increase of the elevation from 5 mm in experiments 8 and 9 to 8 mm in experiments 10 and 11, the double arc still occurs as can be seen from Table 2 as well as Figs. 23–26. Although the elevation has been increased the same as the inter-wire distance, its effect is still not fully eliminated.

However, this may not necessarily mean that an increased elevation does not reduce the chance for a double arc. While further studies are needed to gain definite conclusions, the authors would not further increase the elevation because it would cause the length of the GTA further increases to reduce the stability of the GTA. Hence, the inter-wire distance should be 2 mm as in experiments 1–5. The effort trying to increase the elevation to overcome the effect from increased inter-wire distance should be discouraged.

Conclusion

- The proposed cross-arc process can control heat input and mass separately as well as improve wire melting efficiency, and it can be established and maintained stably using two carbon electrodes to replace the wires.
- The GTA current, inter-wire arc current, and inter-wire distance are all important parameters determining the success to establish and maintain a stable cross arc.
- Increasing the GTA current improves the stability of the cross arc because of the improved conductivity in the inter-wire opening provides a necessary condition to establish the inter-wire arc.
- The inter-wire arc current affects the stability of the cross arc in relatively complex ways. In particular, increasing the inter-wire arc current helps ionize the shield gas to better maintain the conditions to sustain the cross arc. However, it also increases the deviation of the GTA, possibly causing an extreme enough deviation to extinguish the GTA, which serves as a necessary condition to maintain a stable cross arc.
- The length and maximum column diameter of the inter-wire arc increases with the inter-wire distance. An increased distance degrades the conditions to establish and maintain the inter-wire arc and increases the chance for a double arc.

Since this first preliminary study uses two nonconsumable carbon electrodes in place of two filler metal wires, future work will use wires to establish the cross-arc process. To this end, the associate metal transfer process will be studied first and controlled to maintain a stable condition for cross-arc welding.

Acknowledgments

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Competitive Wetting in Active Brazes

The presence of Al in the alloy enhances the spreading of Ag, while the Ag inhibits the spreading of Al

BY M. CHANDROSS

ABSTRACT

The wetting and spreading of molten filler materials (pure Al, pure Ag, and AgAl alloys) on a Kovar™ (001) substrate was studied with molecular dynamics simulations. A suite of different simulations was used to understand the effects on spreading rates due to alloying as well as reactions with the substrate. The important conclusion is that the presence of Al in the alloy enhances the spreading of Ag, while the Ag inhibits the spreading of Al.

KEYWORDS

- Active Brazing • Wetting • Spreading • Computer Simulations
- Metals and Alloys • Molecular Dynamics

Introduction

Ceramics are highly desirable structural materials because of their excellent resistance to wear and corrosion, as well as their ability to withstand high temperatures. However, low fracture toughness and lack of ductility can limit applications, particularly when parts may be exposed to high mechanical and thermal stresses. Metals often perform better under such conditions, leading to the use of a combination of metals and ceramics to meet design goals that necessitate the formation of high-quality, strong seals.

Bonding of metals to ceramics can be accomplished through various different manufacturing processes, but active braze joints are preferred, particularly in high-temperature applications. In these cases, the ductility of the filler material can accommodate residual stresses generated during the joining of materials with different coefficients of thermal expansion (CTE). Active metal additives in the filler material (e.g., Ti, Zr, etc.) can assist with the wetting of the metals on the ceramic surface itself.

The details of the interfacial reactions between ceramics and metals remain only nominally understood. An improved understanding of these reactions can help with the choice of additives in the filler material, as well as geometric considerations for the parts themselves. A crucial component of the mechanism behind active brazing is the wetting and spreading of the filler material on the disparate metal and ceramic surfaces, and how this process changes with additives. Wetting phenomena have been the subject of a number of recent review articles, including those that focus on general wetting (Ref. 1), dissolutive (i.e., reactive) wetting (Ref. 2), and the dynamics of precursor films (Ref. 3).

A particular issue of concern with braze joints is runout (braze alloy flows out of the joint) (Ref. 4). This is a result of instabilities in the wetting and spreading of the filler material. While runout can negatively impact the cosmetics of a joint, both mechanical strength and hermeticity can also be affected through residual stresses or unfilled regions in the joint clearance, respectively. Modifications to the geometry of the joint, the chemical composition of the braze alloy, and the overall processing temperatures have been investigated as methods to reduce or eliminate runout, but have met with limited success. One of the goals of this study was to determine chemical driving forces that may lead to runout, in order to better engineer the braze alloy and the joint materials.

The present work addresses wetting and spreading as it applies to active brazing. Molecular dynamics simulations were used to study the wetting and spreading of a liquid braze filler material on Kovar™ substrates (Ref. 5). Kovar™ is a Fe-Ni-Co alloy, with other species at the sub-percent weight composition level. Kovar™ has a low CTE that allows it to be brazed to glasses and ceramics, providing hermetic seals. For the remainder of this work, the term

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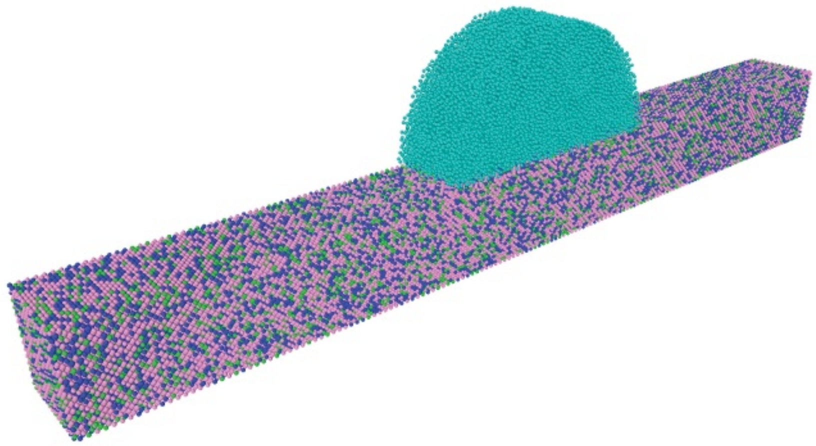

Fig. 1 — Rendering of the initial state of a simulation of pure Ag spreading on Kovar™. Ag atoms are colored cyan, Fe are pink, Ni are blue, and Co are light green.

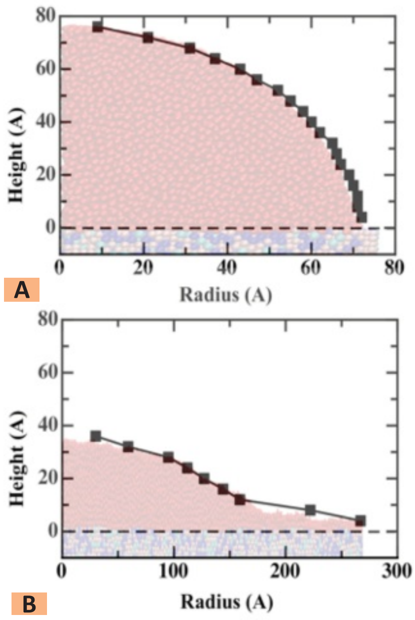

Fig. 2 — Binned data indicating the drop profile for pure Al on fixed Kovar™ after the following amounts of simulation time: A — 0 ns; B — almost 9 ns. Semi-transparent snapshots of the simulations are shown to indicate the correspondence of the profile to the atomic configuration. Discrepancies are due to image scaling issues combined with the plotted location of a point for a single 4 Å bin.

Kovar™ will be used to refer to the model alloy Fe(55)Ni(28)Co(17).

While brazing to Kovar™ has been studied experimentally (Refs. 6–9), simulations of the entire braze joint are difficult to perform, due to the lack of availability of atomistic potentials that simultaneously describe both metals and ceramics. This stems, in part, from the different electronic natures of the two materials. The present study focuses on the metallic base material of the braze joint. While experiments have shown that the presence of both the ceramic and the metal are necessary for runout to occur, it has also been found that Kovar™-Kovar™ joints with Al added to the filler material can exhibit this phenomenon. The filler material itself is predominantly silver, with small amounts of Cu and Zr (Ref. 8). In the braze joint, a reduction-oxidation reaction occurs between the Zr and the ceramic (Al_2O_3) base material, resulting in the formation of ZrO_2 at the ceramic. Elemental Al is released from the ceramic, and becomes incorporated in the molten filler material. Because it is not currently feasible to simulate this entire reaction, and Al in the filler material is necessary to model runout, this work instead studied a filler material with Al already incorporated and the Zr and Cu components omitted. This approximation is justified, because Cu does not play a role, and while the Zr does, it is sufficiently well understood that it can be neglected (Ref. 1). By studying the behavior of pure metals as well as the alloy, a better understanding of the mechanisms responsible for the brazing process can be developed.

Previous studies have investigated the dynamics of wetting in metal systems (Refs. 10, 11) with a stronger focus on spreading rates, and comparisons to molecular kinetic theory (Ref. 12). Some earlier work compared the results of reactive to nonreactive systems in the case of Ag on Cu (Refs. 13, 14), and a CuAg alloy on Cu (Ref. 14). The latter simulations are closest in spirit to the present work, except for the presence of the substrate material in the liquid drop. The system studied here is inherently more complex (with two components in the filler material, and three in the substrate) leading to an interplay between the elements and results that are challenging to interpret in the context of wetting theory. Therefore, no attempt to study the details of the spreading rates or contact angles was made, and instead this work focused on the effects of substrate interactions and competitive wetting of the braze filler components.

Simulation Details

Large-scale molecular dynamics (MD) simulations were used to model the spreading of liquid filler material on a Kovar™ substrate. The LAMMPS simulation code was used with a timestep of 1 fs and a velocity Verlet integration scheme. All simulations were performed at the experimentally used brazing temperature of 1250 K, which is maintained through the use of a Langevin thermostat.

The embedded atom method (EAM) was used, which is related to second moment tight binding theory, and approximates the electron density through the use of an "embedding" term. The EAM is particularly well suited for atomistic simulations of metals, and many potentials exist that have accurately predicted mechanical and structural properties. The EAM potentials were developed by Zhou et al. (Ref. 15), using a normalization procedure that allows for the mixing of multiple components in the simulation. Given the complexity of the current system (Fe, Ni, Co, Ag, and Al), the availability of atomic potentials is quite limited. These specific potentials were fit to shear moduli, elastic anisotropy ratios, and sublimation energies with approximate fits to vacancy formation energies (Ref. 16). While this specific multicomponent alloy potential does not appear to have been previously studied, the potential database used to create it has successfully predicted enthalpies of solution (Ref. 15), which can be used to fit alloy potentials. While a potential specifically created for this alloy would likely provide more quantitative results, it is expected that the alloy interactions generated with this method are acceptable approximations.

The Kovar™ substrate was created from an initial block of pure, single crystal FCC Fe, with the (001) face exposed. Atoms in the substrate were randomly replaced with Ni and Co to form the desired composition. This substrate was then equilibrated at the brazing temperature. Calculated density profiles of the various components demonstrate that the species are thoroughly mixed. Initial simulations held the atoms in the substrate fixed (i.e., forces on the atoms are calculated and then discarded). This allows for study of the wetting of the separate components without the complication of chemical reactions between the filler material and the substrate. Results of wetting simulations with a mobile (i.e., reactive) substrate are presented second, since they are best understood in the context of the results of the initial nonreactive simulations.

The liquid metal was created from an equilibrated bulk sample, in which pure FCC metal was melted and held at the braze temperature of 1250 K. This procedure was duplicated for pure Ag and pure Al samples. Creating the alloy began with the pure Ag sample, followed by random substitution of 15 at.-% of the Ag atoms with Al atoms, and a final re-equilibration. Calculated atomic density profiles show that the Al is well incorporated in the Ag.

The wetting simulations were designed to mimic sessile drop experiments, with one caveat. While full 3D simulations, in which a hemispherical drop of liquid metal was allowed to spread on the substrate, have been performed, it was determined that it was feasible to increase the simulation size without affecting relative spreading rates by instead moving to a quasi-2D simulation. In this geometry, an infinite half-cylinder of liquid spreads on a substrate that can now be much larger in the direction of spreading. The substrate is 56.2 nm in the spreading direction (x), 5.4 nm thick (y), and 5.1 nm perpendicular to the spreading direction (z). The liquid drop initially had a 15-nm radius, and a 5.4-nm thickness to match the substrate. A snapshot of the initial state of the simulation is shown in Fig. 1.

The half cylinder of molten alloy was allowed to spread dynamically on the substrate, in most cases, until the liquid had fully wet the Kovar™. In order to analyze the dynamics of spreading, histograms of the liquid atoms as a function of height through the simulation box were calculated. The bins were 4 Å thick, and for each bin, the radius that contains 95% of the atoms in that bin was found, and plotted as a function of simulation time. In this geometry, the radius refers to a linear distance from the middle of the half-cylinder in the direction of spreading.

Figure 2 shows examples of the binned data for pure Al on fixed Kovar™ for the drop (A) at the beginning of the simulation and (B) after almost 9 ns of simulation time. The profile in Fig. 2A shows the initial curved profile of the drop as can also be seen in Fig. 1, while Fig. 2B shows the drop has spread with a precursor foot that formed near the Kovar™ substrate.

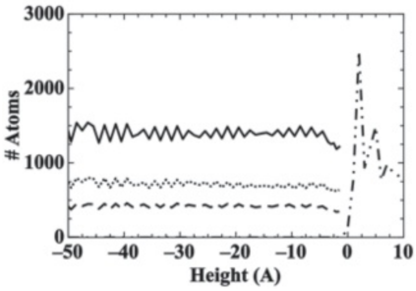

Fig. 3 — Density profile of pure Al spreading on a fixed Kovar™ substrate after ~9 ns of simulation time. Atomic types are shown as Fe (solid line), Ni (dotted line), Co (dashed line), and Al (dot-dashed line).

Results – Fixed Substrate

Spreading simulations were performed for pure Al on a fixed Kovar™ substrate. Density profiles for each atomic type are shown in Fig. 3 after ~9 ns of spreading. These density profiles demonstrate that the Kovar™ was reasonably well mixed during the simulation. The liquid Al profile shows a density peak near the surface (corresponding to the first layer of Al on the substrate) with an approximate width of 4 Å, indicating the proper bin size for analysis of the spreading dynamics.

Figure 4 shows the "drop" radius as a function of time for pure Al spreading on fixed Kovar™ for the lowest three nonzero bins. The bin from -4 to 0 Å has been calculated, and indicates no interdiffusion (note that the top of the Kovar™ substrate is at approximately 0 Å), as there are no Al atoms in this bin. This is expected for simulations in which reactions with the substrate are forbidden. In the figure, the first bin from 0 to 4 Å shows the formation of a precursor foot that quickly spreads and covers the entire substrate by approximately t = 3 ns. Above this layer, from 4 to 8 Å, there is some indication that a second foot forms and spreads but fails to cover the substrate. The dynamics of the two bins above 8 Å, 8 to 12 Å, and 12 to 16 Å (not shown) are similar, indicating that this is the spreading behavior of the bulk drop (i.e., not associated with a precursor foot).

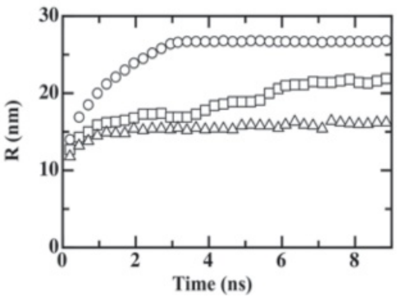

Fig. 4 — Binned radius as a function of time for pure Al on fixed Kovar™ for bins from 0 to 4 Å (circles), 4 to 8 Å (squares), and 8 to 12 Å (triangles).

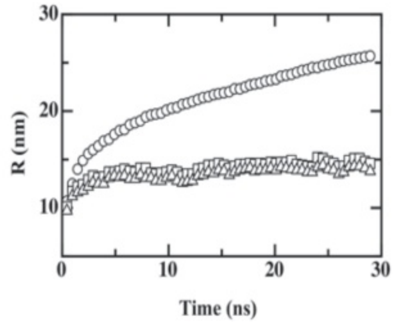

Fig. 5 — Binned radius as a function of time for pure Ag on fixed Kovar™ for bins from 0 to 4 Å (circles), 4 to 8 Å (squares), and 8 to 12 Å (triangles).

The spreading of a pure Ag drop on the same fixed Kovar™ substrate is substantially different, as shown in Fig. 5. While a precursor foot does extend before the spreading of the main

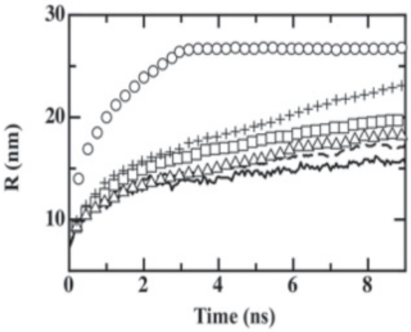

Fig. 6 — Binned radius as a function of time on fixed Kovar™ from 0 to 4 Å above the surface of pure Al (circles), pure Ag (squares), Al in the alloy (triangles), and Ag in the alloy (plus signs). Also shown for comparison are the bulk drop spreading of Al in the alloy (solid line) and Ag in the alloy (dotted line). The bin representing the bulk drop is taken from 8 to 12 Å above the surface.

drop, the motion of this foot is slower by a factor of approximately 10 as compared to the pure Al, and barely covers the substrate after 30 ns of simulation time. The height of the foot, however, is similar to that in Al. The next two 4 Å layers from 8 to 12 Å and 12 to 16 Å (not shown) show the spreading of the main drop.

Next, the wetting and spreading of a binary alloy with the composition 85Ag-15Al (at.-%) was examined. The behavior of each individual component of the alloy was assessed, and the results were found to be nonintuitive when compared to the pure metals. Figure 6 shows the spreading of the precursor foot region as a function of time for four different simulations: 1) pure Al, 2) pure Ag, 3) Al in the 15Al-85Ag alloy, and 4) Ag in the 15Al-85Ag alloy. These simulations demonstrate that the presence of Ag in the alloy greatly inhibits the spreading of Al, which spreads at a rate close to the pure Ag. These results also show some enhancement of the spreading of Ag in the alloy (as compared to the pure metal) due to the presence of the Al. Also shown for comparison is the spreading of the bulk drop region for the two different components in the alloy. This demonstrates that there is indeed a precursor foot in the alloy, the leading edge of which is composed more of Ag than of Al. Nevertheless, the percentage of Al in the foot is higher than one would expect from

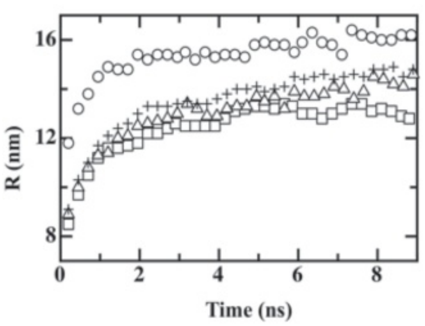

Fig. 7 — Spreading of the bulk drop from 8 to 12 Å above the Kovar™ surface. Shown are pure Al (circles), pure Ag (squares), Al in the alloy (triangles), and Ag in the alloy (plus signs).

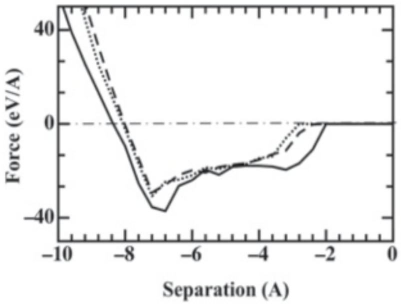

Fig. 9 — Force vs. separation curves for pure Al (solid line), pure Ag (dashed line), and the alloy (dotted line). Curves have been averaged to appear smoother and reveal more detail.

the alloy concentrations.

Figure 7 shows the spreading of the bulk of the drop for both components in the alloy as well as the pure Al and Ag systems. From this figure, again it is clear that the presence of Ag inhibits the spreading of Al, although in the case of the bulk drop, it is only in the initial stage of spreading (less than 1-ns simulation time) that the pure Al spreads more quickly. After this time, the rate of spreading is similar to all other species shown.

The disproportionate amount of aluminum at the Kovar™ substrate is clear from the ratio of the number of Al atoms to Ag atoms as a function of height through the simulation box. In Fig. 8, this calculated ratio is shown at the beginning of the simulation and after 15 ns of simulation time. From these graphs, it is clear that although the Al is well mixed in the Ag at the beginning of the simulation, the Al rapidly and preferentially moves to the interface. It is reiterated that there are

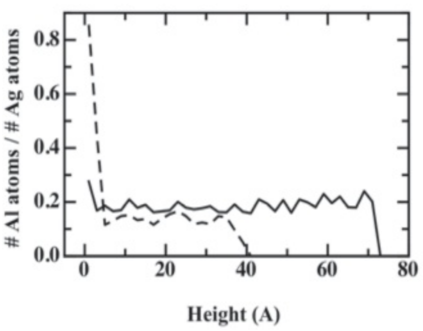

Fig. 8 — Ratio of number of Al atoms to number of Ag atoms as a function of height above the Kovar™ surface at simulation times of 0 ns (solid line) and 15 ns (dashed line).

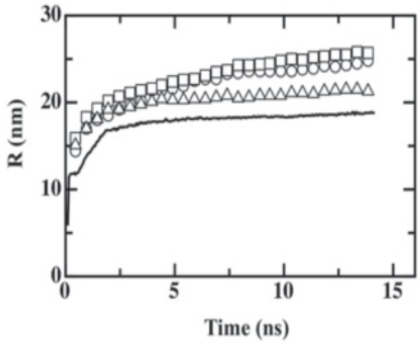

Fig. 10 — Binned data for pure Al on the mobile substrate. Data are shown for bins from –4 to 0 Å (solid line), 0 to 4 Å (circles), 4 to 8 Å (squares), and 8 to 12 Å (triangles).

no reactions possible in these simulations, indicating that either the Al is preferentially attracted to the Kovar™ substrate, or that a difference in surface tension is leading to segregation.

A calculation was made of the surface tension, γ, of both of the pure metals and the alloy through the mechanical definition of the surface stress (Ref. 17). The calculated values of γ are incorrect, including the ordering, for both metals [γ(Ag) = 725 mN/m and γ(Al) 874 mN/m] compared to experiment [γ(Ag) = 917 mN/m and γ(Al) = 814 mN/m (Ref. 18)]. The difficulty in predicting surface tensions with EAM has been documented previously (Ref. 19), and is not unexpected. While the incorrect ordering, however, could lead to anomalous behavior of the two metals in the alloy, the ratio of γ(Ag)/γ(Al) is close to 1.0 in both cases (0.83 for simulations and 1.1 for ex-

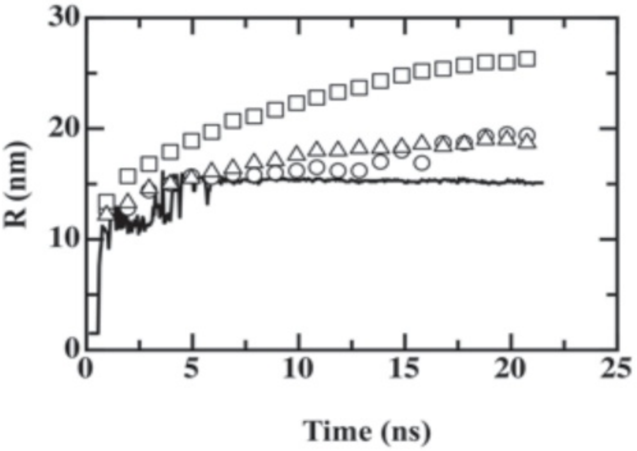

Fig. 11 — Binned data for pure Ag on the mobile substrate. Data are shown for bins from –4 to 0 Å (solid line), 0 to 4 Å (circles), 4 to 8 Å (squares), and 8 to 12 Å (triangles).

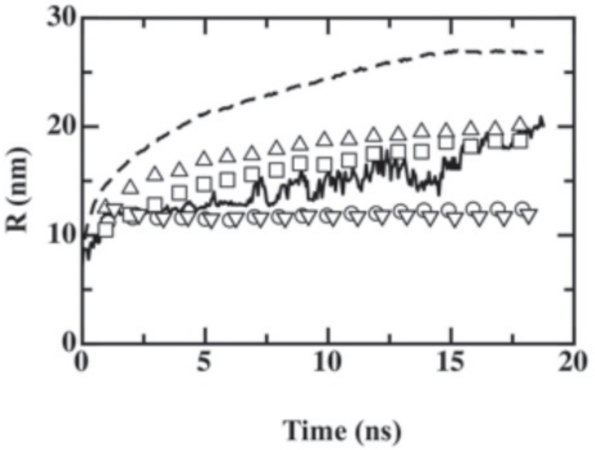

Fig. 12 — Binned data for the separate components of the 85Ag-15Al alloy on mobile Kovar™. Data shown for Al are –4 to 0 Å (circles), 0 to 4 Å (squares), 4 to 8 Å (up triangles) and for Ag –4 to 0 Å (down triangles), 0 to 4 Å (solid line), 4 to 8 Å (dotted line).

periments), and thus these effects should be weak.

To understand the effects of surface tension on wetting and spreading, it is necessary to be able to calculate the liquid/solid interfacial tension. While methods do exist for calculating this in simple systems (Ref. 20), extending these methods to species like metals, that are characterized by collective interactions, is challenging. Because of this difficulty, it was decided to calculate force-separation curves for the various liquids approaching the Kovar™ substrate. For these simulations, a slab of liquid metal (either pure Al, pure Ag, or the Al15-Ag85 alloy), infinite in the x-y plane but with thickness ~ 3 nm in the z dimension, was equilibrated. The slab was then brought into contact with a Kovar™ substrate at a fixed velocity of 2 m/s, and the force on the liquid was measured as a function of separation.

Figure 9 shows approach curves for pure Al (solid lines), pure Ag (dashed lines), and the Al15-Ag85 alloy (dotted lines). The zero of separation is arbitrary, and serves as a reference point. Figure 9 shows clearly that the Al has a much stronger adhesive interaction with the substrate. This point can be seen both in the earlier start of adhesive forces, as well as the larger magnitude of the adhesion. Stronger adhesion leads to the preferential movement of the Al to the substrate, which enhances the movement of Ag. While this adhesion is an atomistic phenomenon, it likely implies a strong tendency for the Al to alloy with the constituents of the Kovar™, forming the experimentally observed aluminides (Ref. 4).

Results – Mobile Substrate

The wetting and spreading of the Al, Ag, and 15Al-85Ag alloy on mobile Kovar™ (i.e., in which reactions with the substrate are allowed) follow a similar pattern as on the fixed substrate. In Fig. 10, binned data are shown for pure Al spreading on the mobile substrate. Nevertheless, when compared to Fig. 4, which shows the wetting and spreading of pure Al on the fixed substrate, several differences are immediately apparent. On the mobile substrate a line was included that indicates the spreading of Al below the surface of the substrate, from –4 to 0 Å. These data indicate that the Al reacts with the substrate near the initial location of the drop, but does not spread significantly beyond the initial reaction zone. The next two higher bins, from 0 to 4 Å and from 4 to 8 Å, have spreading behavior nearly identical to each other, reaching the edge of the substrate in less than 15 ns. When compared to the highest bin shown, it can be inferred that the two intermediate bins show some advanced spreading of a rather thick precursor foot above the reaction zone.

The spreading behavior of the pure Ag on the mobile substrate, shown in Fig. 11, is qualitatively similar with the notable exception of the bin from 0 to 4 Å, which spreads only slightly more quickly than the subsurface bin. This implies that the Ag reacts strongly with the substrate throughout these first two layers, and only above this (i.e., from 4 to 8 Å) can a foot begin to spread. This interpretation is further validated through analysis of the spreading of the separate components in the 15Al-85Ag alloy, shown in Fig. 12. Both below (–4 to 0 Å) and at (0 to 4 Å) the surface, Al and Ag show similar dynamics. It is only in the next higher layer that the foot dynamics are revealed, where it is clear that Ag in the alloy spreads significantly faster than Al in the alloy, and comparison to Fig. 11 shows that Ag in the alloy spreads faster than the pure Ag alone.

The changes in spreading rates in the alloy as compared to the pure components can only be ascribed to the competitive wetting of the two constituents. In Fig. 13, a comparison is made between the spreading of the precursor feet in the pure metals and the separated components of the alloy. For the reasons discussed above, the bin used to describe the foot is from 4 to 8 Å. While in the case of pure metals, Al spreads somewhat faster than Ag, competitive wetting in the alloy leads to significantly different behavior. The Al in the alloy spreads much more slowly than either of the pure metals, or the

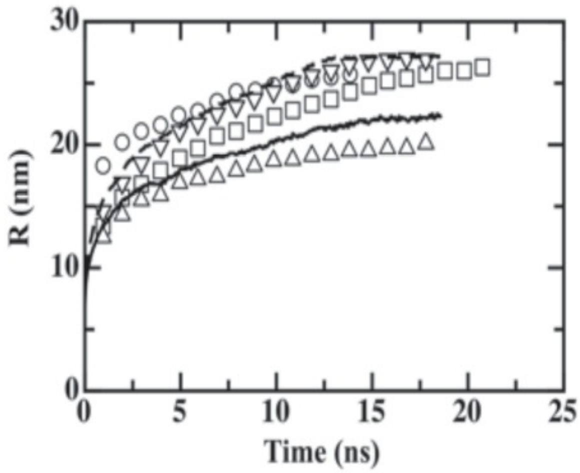

Fig. 13 — Spreading of the precursor foot for pure Al (circles), pure Ag (squares), Al in the alloy (up triangles), and Ag in the alloy (down triangles). Also shown are results for Al (solid line) and Ag (dashed line) as separated components in a 30Al-70Ag alloy.

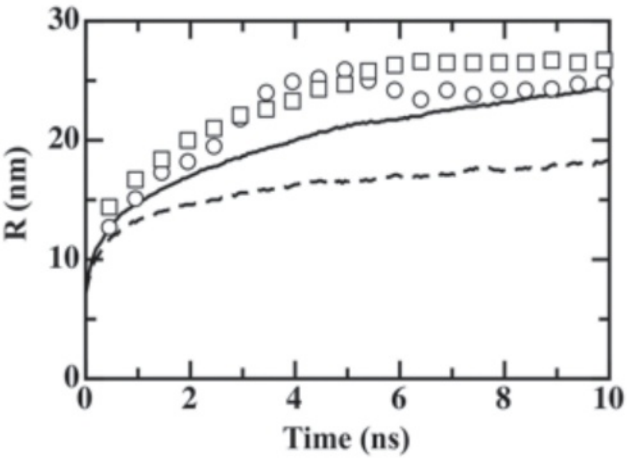

Fig. 14 — Binned data for Ag in the 85Ag-15Al alloy spreading on a mobile Kovar™ substrate. Data shown are for spreading over a monolayer of Al from 4 to 8 Å (circles), 8–12 Å (squares), and without the monolayer, 4–8 Å (solid line) and 8–12 Å (dashed line).

Ag in the alloy, while the Ag in the alloy spreads at the rate of pure Al. These results suggest that it is possible to control the speed at which certain components of an alloy spread by tailoring the composition of that alloy. Wetting can also be affected by pretreating the faying surface with a coating that changes spreading behaviors.

To investigate this concept, two cases were studied, the first was an alloy with a higher Al content, namely 30Al-70Ag, and the second by prewetting the surface with a monolayer of pure Al. The results of the spreading of the 30Al-70Ag alloy are also shown in Fig. 13, where it is clear the increase of the Al content has essentially no effect on the spreading of the Ag, but results in faster spreading of the Al itself. As the percentage of Al in the filler material increases, so should the rate of spreading of the Al, approaching that of the pure metal.

The effects of pretreating the surface by creating a Kovar™ substrate with a monolayer of Al already pre-wet on the surface were investigated. This substrate was created by starting from the simulations of pure Al spreading on the fixed substrate. When the Al had fully spread on that substrate, a monolayer of Al atoms was removed from the top of the fixed Kovar™, and added to the top of a mobile Kovar™ substrate. This simulation was then equilibrated before the half-cylinder of 15Al-85Ag alloy was placed on top and allowed to spread. In Fig. 14, the results of the Ag component of the alloy spreading on the monolayer are shown, and compared to the spreading of Ag in the same alloy on the mobile surface without the pre-wet layer. The presence of the monolayer makes the identification of the correct bin for the foot slightly more difficult, as the bin from 4 to 8 Å shows some irregularities. Therefore, the data from the next higher bin have also been included. It is clear, especially in comparison to the data without the pre-wet layer, that an existing coating of Al causes the Ag in the alloy to spread significantly faster than over an untreated substrate. While this effect has been seen previously and ascribed to lubrication of the substrate by the precursor film (Ref. 3), the present work seems to point at a different explanation that is addressed in the next section.

Discussion

The results presented here show the Al liberated from the oxidation-reduction reaction at the ceramic surface quickly moves through the braze filler material to the Kovar™ surface. This effect seems to be mostly due to a higher affinity of the Al for the Kovar™ (as compared to the Ag that forms the bulk of the filler material), although surface energy effects cannot be completely ruled out at the present time. Experiments found that Al has a lower surface energy than Ag, and thus would be expected to preferentially coat a surface. In our simulations, however, the situation is reversed. The calculations presented here find that the Al has a slightly higher surface energy than Ag, and would tend to allow the Ag to cover the surface. In both simulations and experiments, however, the surface energies are close to each other, implying that this effect would not be very strong. Experiments can be strongly affected by oxidation, which can alter the surface energies, but these calculations indicate that other factors dominate the spreading.

Regardless of the cause, the presence of Al at the Kovar™ surface in all cases enhances the rate of spreading of the Ag, and it is likely that this is the source of the instability leading to runout. This could be ascribed to a lubrication effect, as discussed elsewhere (Ref. 3), but this does not appear to be the case in our simulations. Additional simulations in which a thin monolayer stripe of Al is present on the Kovar™ surface along the wetting direction were performed. This stripe was 1 nm in width (i.e., perpendicular to the spreading direction) along the entire length of the substrate. With the 15Al-85Ag alloy on top of this prepared substrate, there is no enhancement of the Ag spreading rate over the system in which the stripe was not present. Examination of snapshots of these simulations show the Ag preferentially moves along the edges of the stripe, rather than on top, implying that a lubrication mechanism, if it exists in this system, is not a strong effect. Note that the diffusivity of Al on the Kovar™ substrate necessitates that these "stripe" simulations be performed with a fixed substrate (and stripe) to maintain the structure of the pre-wet Al stripe.

In previous simulation work, it has been found that spreading is enhanced in reactive systems (Refs. 13, 14). While the present simulations show a slight enhancement of the spreading of Ag on a mobile substrate compared to a fixed substrate (not shown here), this is for the pure metal only. The Ag component of the 15Al-85Ag alloy, on the other hand, shows essentially no difference in spreading behavior on the two substrates. Similarly, the Al in the alloy spreads at nearly identical rates on the fixed and mobile substrates. The pure Al, in contrast, shows a significant decrease in spreading on the mobile substrate compared to the fixed. These results imply that the changes in spreading rates between reactive and nonreactive systems is strongly dependent on the specific elements, and more work will need to be performed to understand these results.

Conclusions

In this work, the wetting and spreading of pure Al and Ag on a (001) Kovar™ substrate was studied, as well as the spreading of two different Al-Ag alloys, with the goal of understanding the cause of filler material runout in active brazes. The results presented show that while in the case of pure metals Al spreads more quickly than Ag, the multicomponent interactions in the alloy lead to nonintuitive results. On both frozen substrates (in which interactions between the filler material and the substrate are suppressed) and mobile substrates (in which all interactions are allowed to proceed), the presence of Al in the alloy leads to faster spreading of the Ag. It is proposed that this competitive effect is the mechanism behind runout. Elemental Al is liberated from the Al_2O_3 during the brazing process, and quickly migrates through the braze alloy to the Kovar™ surface. The presence of Al at the Kovar™ results in faster spreading of the Ag in the braze alloy, leading to potential runout. While these results are atomistic in nature, what is clear is that there exists one aspect of the wetting and spreading that is atomistic in nature (the precursor foot), and one that is more macroscopic (the spreading of the bulk drop on top of this precursor foot), and thus representative of experiments. The differences in spreading rates, both in the precursor foot as well as in the bulk drop, should accurately reflect the spreading seen experimentally, within the accuracy of the potentials used.

Acknowledgments

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Laser-Vision-Based Measurement and Analysis of Weld Pool Oscillation Frequency in GTAW-P

An image-processing algorithm was developed for extracting the pool oscillation frequency, and several experiments with varying weld joint penetration for traveling and stationary weld pools were conducted

BY Y. SHI, G. ZHANG, X. J. MA, Y. F. GU, J. K. HUANG, AND D. FAN

ABSTRACT

An innovative laser-vision-based sensing method is proposed to measure weld pool oscillation frequency in pulsed gas tungsten arc welding (GTAW-P). A low-power five-line laser pattern is projected onto the entire weld pool surface as well as its reflection is intercepted by an imaging plane and captured by a high-speed camera. By observing and analyzing the change of the captured laser images during the base current period, it is found that the variation of reflected laser lines is periodic and has a strong relationship with the weld pool oscillation. A novel image processing algorithm is also developed for extracting the pool oscillation frequency. Several experiments with varying weld joint penetration for traveling and stationary weld pools were conducted, and the oscillation frequency extracted. Experimental results show that the weld pool oscillation is capable of being observed by this method. The extracted frequencies were verified, and the oscillation frequency of partial penetration is higher than the complete joint penetration, along with an abrupt transition. The image processing method and algorithm demonstrated good robustness and effectiveness, and could be used to monitor and control weld joint penetration in real time.

KEYWORDS

- Pulsed Gas Tungsten Arc Welding (GTAW-P) • Weld Pool Oscillation Frequency
- Image Processing Laser Vision • Weld Joint Penetration
- Fast Fourier Transform (FFT)

Introduction

In recent years, the trend in high-productivity and high-quality welding has been toward process automation. This has stimulated the increased use of automation and associated systems. When replacing a manual welding machine with an automated system, it is necessary to provide the control system with information about the location of the weld bead and weld pool geometry. Therefore, sensing and modeling are becoming the key issues for successful implementation of weld process control. However, a particular problem that occurs in the case of the gas tungsten arc welding (GTAW) process is the difficulty of consistently obtaining complete joint penetration over the entire length of the weld joint. Consistent, complete joint penetration is an essential property of a good weld, especially in the case of the root pass of a thick plate or fillet weld under variable load conditions. In addition, weld joint strength, i.e., tensile strength and fatigue strength, is regarded as another standard of welding quality. The factors affecting the weld joint strength, which include external loads, cross-sectional area of the weld bead, etc., have been investigated and it was found that the cross-sectional area plays an important role in determining the weld joint tensile strength (Refs. 1, 2). Incomplete penetration/fusion can reduce the effective working cross-sectional area of the weld bead, which may reduce the weld joint strength when keeping the external loads constant. An incomplete penetration defect could also lead to serious stress concentrations in case of the fillet or T-joints. The presence of stress concentrations cause the later cracking and reduce fatigue life. However, too much penetration results in melt-through. Repairing inadequately penetrated welds is time consuming and costly. This makes the measurement and real-time process control of weld joint penetration highly attractive, especially in the case of welding austenitic stainless steel where so-called cast-to-cast variation in penetration may occur. Many attempts have been made to monitor and control the weld joint penetration using various sensing methods, such as temperature field (Refs. 3, 4), machine vision (Refs. 5–8), ultrasonic (Ref. 9), arc acoustics (Refs. 10, 11), radiography (Ref. 12), and others. Machine-vision sensing methods that provide direct feedback information of the weld pool geometry have been increasingly investigated. Particularly, in the manual GTAW process, a skilled welder can observe and obtain suffi-

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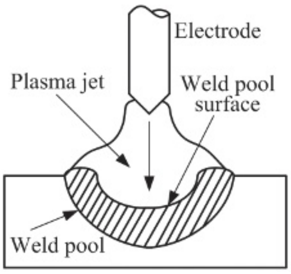


Fig. 1 — Illustration of weld pool surface depression due to plasma jet force.

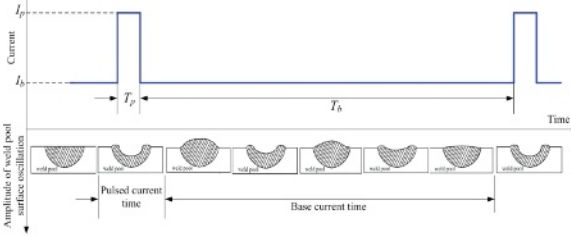


Fig. 2 — Current waveform and illustration of weld pool oscillation in one pulsed current period. (I_p is the pulsed current; I_b is the base current; T_p is the pulsed current time; T_b is the base current time.)

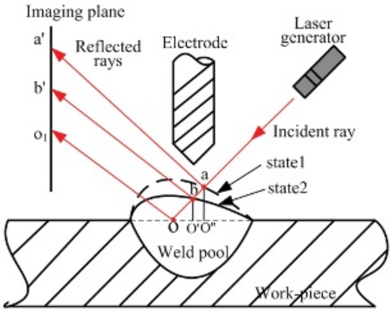


Fig. 3 — Illustration of laser-vision-based measurement principle.

cient information from the weld pool surface to estimate the degree of weld joint penetration, and then adjust the position or traveling speed of the weld torch to achieve a complete joint penetration (Ref. 13). The top and backside geometry of weld pool was acquired by a charged coupled device (CCD) camera, and its characteristic parameters were obtained by a specialized algorithm. Based on the above information, the neural network models of the top geometric parameters and the backside width of weld pool were established, and the control experiments were conducted on the workpiece of varying widths at the length of the direction (Refs. 14–16). Unfortunately, the correlation between the frontside weld pool geometry and the weld joint penetration should be researched further to facilitate real-time penetration monitoring and accurate penetration control of the GTAW process. The robustness of vision-based sensing methods is reduced due to interference from the arc light. Hence, they are not widely applied to practical joint penetration measurement.

Researchers have demonstrated that the oscillation frequency of a weld pool has a strong relationship with its volume size in the stationary GTAW process (Refs. 17, 18). Furthermore, extraction of the oscillation frequency for sensing and control of weld penetration has been a topic of interest since the 1980s (Refs. 19–22). These approaches are based on the principle that the change of arc length, which is caused by the weld pool surface oscillation in the vertical direction, results in a linearly simultaneous change of arc voltage, and the oscillation frequency is obtained by monitoring the arc voltage. However, the small amplitude of weld pool oscillation, which causes an unobvious change of arc length, and the other interferences, such as surface roughness, instability of weld power supply, welding environmental changes, result in poor signal-to-noise ratio (SNR) of the arc voltage. Extracting the oscillation frequency from the arc voltage is very difficult, and can only be applied to the very slow moving/traveling weld pools. Another way to monitor the weld pool oscillation is monitoring the intensity of the arc light as the arc voltage, the arc light intensity is also dependent on the arc length. Yoo et al. (Ref. 23) reported that the arc light sensor has a higher sensitivity compared with the voltage sensor. Barborak et al. (Ref. 24) observed that the sensing through arc voltage can be reliably utilized for travel speeds up to 3.83 mm · s, while the arc light sensor can be used for speeds as high as 6.35 mm · s. In comparison with voltage measurements, however, arc light monitoring is less practical since it requires additional equipment and needs a larger access area. These two methods to monitor the weld pool oscillations frequency cannot completely meet the requirements of the modern high-efficiency welding. Therefore, a rapid, simple, and effective sensing approach needs to be developed for measuring and control of weld joint penetration of the GTAW process in real-time.

Recently, a vision-based sensing system for the GTAW process has been developed in the University of Kentucky Welding Research Laboratory under Dr. YuMing Zhang's supervision (Refs. 25–27). The three-dimensional weld pool surface can be reliably reconstructed in real-time and characterized by its width, length, and convexity (Ref. 28). The weld joint penetration was estimated by using the proposed optimal model and weld pool geometric parameters with an acceptable accuracy (Refs.

Table 1 — Experimental Parameters

Experiment	Pulse Frequency (Hz)	Pulsed Current (A)	Base Current (A)	Average Current (A)	Duty – Ratio (%)	Welding Speed (mm/s)	θ (deg)	D (mm)	L (mm)	Arc Length (mm)	Voltage (V)
1	10	200	90	145	40	1.471	31	50	40	5	21.4
2	7.6	160	90	111.538	40	1.471	31	50	40	5	20.5
3	10	160	80	128	60	0	31	49	40	5	20.9
4	10	220	50	118	40	0	31	49	40	5	20.7
5	10	120	90	102	40	1.471	31	49	40	5	20.3

θ — The angle between laser generator and workpiece; D — Distance from weld tungsten to imaging plane; L — Distance from laser generator center to weld pool center.

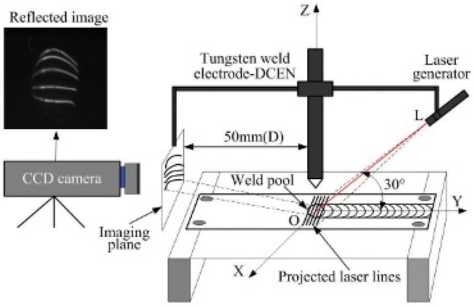


Fig. 4 — Illustration of measurement system of weld pool oscillation in GTAW-P.

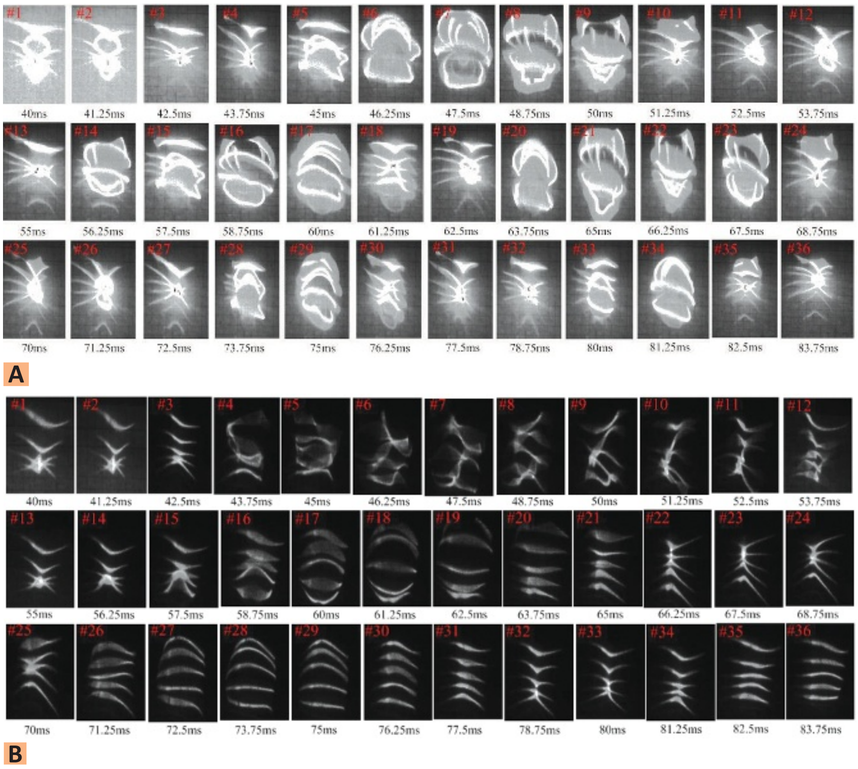


Fig. 5 — Typical reflected laser images of traveling and the stationary welding process. A — Experiment 1, 1.25 ms per frame. Images 1 and 2 are acquired at pulsed current period. Images 3–36 are captured at base current period. B — Experiment 3, 1.25 ms per frame. Images 1 and 2 are acquired at pulsed current period. Images 3–36 are captured at base current period.

29–31). However, for control of weld joint penetration, the welding parameters such as welding current, welding speed, and arc length should be adjusted. It is unclear if these characteristic parameters might be capable of predicting the weld joint penetration with acceptable accuracy when the weld pool varies substantially. In this paper, an innovative method is proposed and applied to monitor the weld pool oscillation, whose fundamental principle is the specular reflection of weld pool surface and the optical magnification of the weld pool oscillation amplitude on the imaging plane. A five-line laser pattern is projected onto the weld pool surface under the electrode at a certain angle that covered the entire weld pool. Then, the reflected laser lines are intercepted by an imaging plane and captured by a high-speed camera with filter components in the pulsed GTAW process. To extract the weld pool oscillation frequency from the captured laser images, a new image-processing algorithm is also proposed and developed. Several experiments with varying degrees of weld joint penetration were conducted and the pool oscillation frequency was extracted. The robustness and effectiveness of the developed image processing algorithm was also demonstrated. The weld joint penetration for traveling and stationary welding was estimated based on the extracted oscillation frequency. The experimental results provide a new way to sense and predict the weld joint penetration from the top side of the weld pools by detecting the weld pool oscillation frequency.

Fundamentals of the Laser-Vision-Based Sensing Method

In this section, the principle of triggering the GTA weld pool surface by pulsed current is detailed based on the phenomenon that the arc creates a plasma jet, traveling from the electrode toward the workpiece. The impingement of the plasma jet on the weld pool surface tends to depress the center of the weld pool, hence providing stimulating energy to the oscillation system (Ref. 32). For clearly observing and investigating the oscillation behavior of weld pool during the GTAW process, pulsed current is utilized, which can produce different magnitudes of arc force imposed on the weld pool surface. During the pulsed current period, the weld pool surface is depressed by the increased arc pressure, and during the base current period, the distortion of weld pool surface gradually restores to its original state since a force balance exists between the external pressure (arc pressure) and the internal pressure (surface tension, gravity, and liquid buoyancy of weld pool) after releasing the pulsed current. The situation is schematically shown in Fig. 1 (Ref. 33).

By choosing a proper waveform of pulsed current, the weld pool surface will be periodically oscillated. The control of weld joint penetration would

Table 2 — The Extracted Oscillation Frequency and the Manual Count Frequency

Experiment	Extracted Frequency (Hz)	Manual Count Frequency (Hz)
1	90~100	96
2	105~110	108
3	70~85	81
4	10~20	16
5	110~125	120

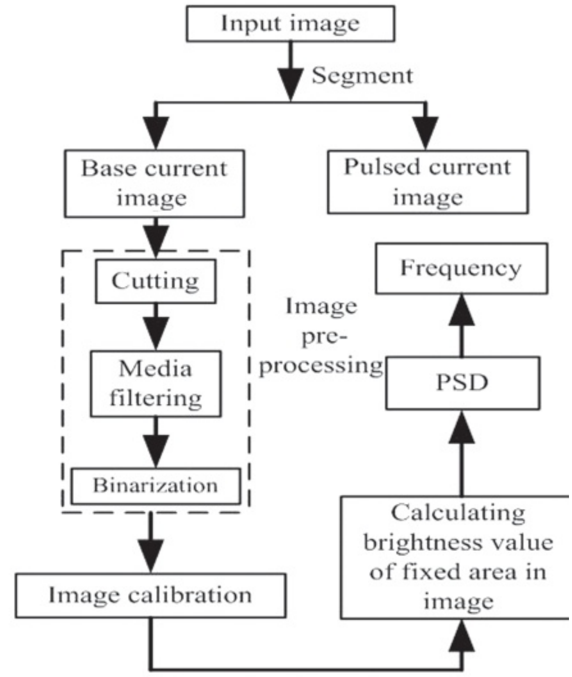


Fig. 6 — Flow chart of the extraction of oscillation frequency.

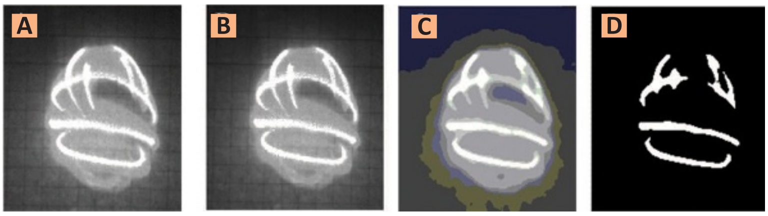


Fig. 7 — Preprocessed images. A —Original image; B — cut image; C — filtered image; D — binarized image.

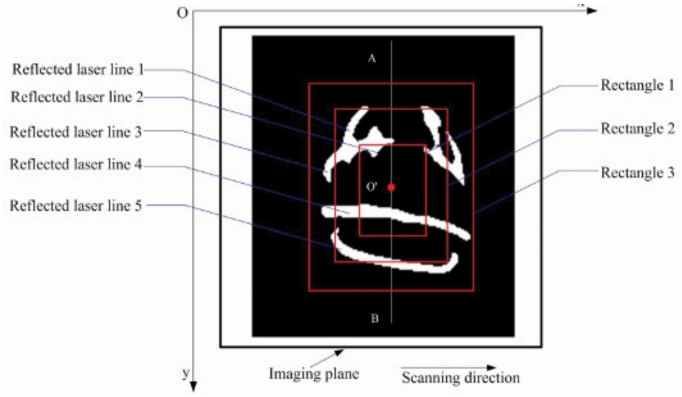


Fig. 8 — Calibration of the binarized image with rectangular window.

thus be carried out through controlling the pulsed current frequency and base current time. The variation of weld pool surface in one rectangular pulsed current period is shown in Fig. 2. After observing the dynamic weld pool surface of the GTA welding process, it can be shown that the vertical oscillation amplitude of weld pool surface is very small and decays rapidly. The weld pool presents a damped oscillation. Therefore, it is very hard to directly measure the weld pool oscillation frequency. Based on the oscillation phenomenon of the weld pool, a novel approach named laser vision is proposed to measure the oscillation frequency of weld pool in this paper — Fig. 3. When the weld pool surface is depressed by the increased arc force during the pulsed current period, the weld pool surface is oscillated by elastic restoring force at the base current period. Figure 3 shows the oscillation states of weld pool surface change from state 1 to 2. The change of the reflected angle of incident laser ray is very obvious, the length of $|ao''|$ is magnified to $|a'o_1|$ and the length of $|bo'|$ is magnified to $|b'o_1|$. As a result, the variable height of weld pool surface can be calculated with geometric transformation, because the arc radiation decays very fast with increasing travel distance while the reflected laser light retains its original intensity, it is possible that not only the reflection of projected laser can be clearly imaged on the interception plane but also the dynamic reflected images of laser lines are captured by the high-speed camera.

Experimentation

Sensing System

The original three-dimensional weld pool surface measurement system is described in Ref. 34. The measurement system has been improved in this work, and is shown in Fig. 4. This system is comprised of a structured-light laser generator, imaging plane, a GZL-CL-22C5M-C high-speed camera produced by Point Grey Research Co., and a composite filter lens that consists of a neutral light-reducing piece and 10-nm band-pass filter centered at a wavelength of 685 nm. A 500-mW StockerYale Lasiris$^{\text{TM}}$ SNF continuous illumination laser with variable focus is used to generate a structured-light pattern, such as a dot-matrix, five lines, etc. The laser pattern is projected onto the weld pool under the electrode at a certain angle and covers the entire weld pool surface. The high-speed camera can acquire 60 to 1800 frames per second and is used to capture the reflected images on the imaging plane (thin glass with a sheet of white paper attached). Without filler metal, the GTAW-P is applied. The welding direction is along the negative Y axis. Being fixed perpendicularly to the workpiece, the welding torch is stationary while workpiece is traversed below. Meanwhile, the laser generator is fixed

Table 3 — Geometric Parameters of Weld Bead Shape

Experiment	Top Width (mm)	Depth (mm)	Forming Coefficient (top width/depth ratio)	Backside Width (mm)
1	8.12	3.00	2.70	5.06
2	5.06	1.12	4.50	0
3	5.10	3.00	1.70	2.08
4	5.12	3.00	1.71	2.12
5	4.14	1.04	3.98	0

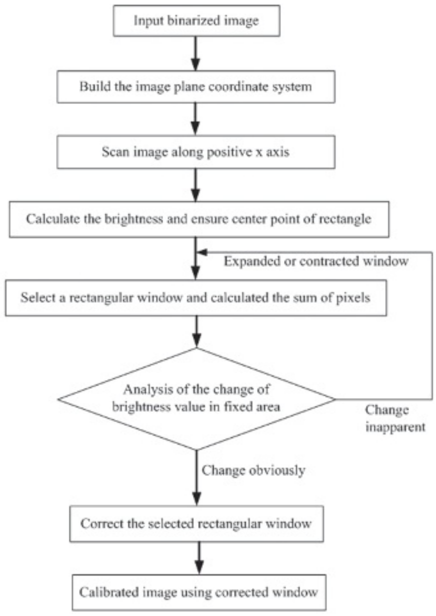
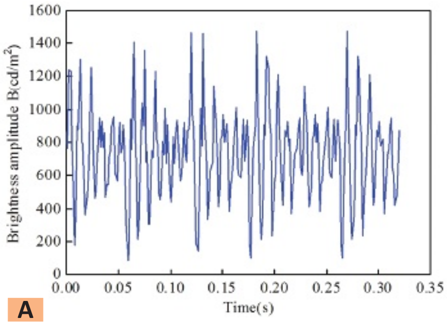
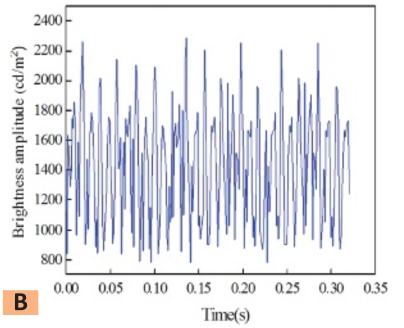

Input binarized image
Build the image plane coordinate system
Scan image along positive x axis
Calculate the brightness and ensure center point of rectangle
Expanded or contracted window
Select a rectangular window and calculated the sum of pixels
Analysis of the change of brightness value in fixed area
Change inapparent
Change obviously
Correct the selected rectangular window
Calibrated image using corrected window

Fig. 9 — Flow chart of automatic selection of a rectangular window.





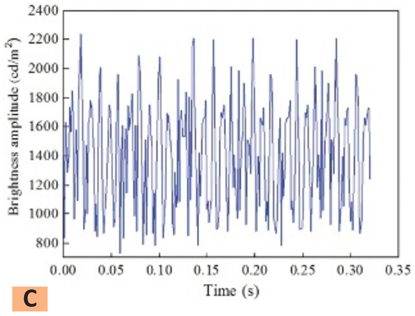


Fig. 10 — Curves of brightness value with different size windows in the time domain of experiment 1. The following pixel windows are shown: A — curve of 81 × 31; B — curve of 121 × 101; C — curve of 181 × 121.

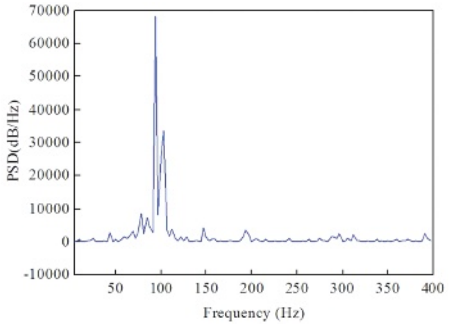


Fig. 11 — Power spectral density curve of experiment 1.

at the backside of welding torch. As the base metal is melted by the arc and forms a liquid weld pool, the specular reflections of projected laser lines occur and are intercepted by an imaging plane fixed vertically at the opposite side of the welding torch. The laser generator is projected onto an OYZ plane at 30 deg with a distance of 40 mm away from welding pool center. The welding torch, laser generator, and imaging plane are carefully aligned. In order to diminish the influence of strong arc light, the high-speed camera is fitted with a 10-nm band-pass filter centered at a wavelength of 685 nm. Thus, most of the arc radiation interference, which is distributed along the entire visible wavelength spectrum, is eliminated.

Experimental Results

Several experiments with the Table 1 parameters have been conducted to measure the weld pool oscillation frequency. Three-mm-thick Type 304 stainless steel plates are used as the workpiece. Typical reflected laser images from the traveling and stationary GTA weld pools are, respectively, shown in Fig. 5. The sampling frequency of the high-speed camera was 800 Hz. The shielding gas was pure argon and its flow rate set at 15 L/min. Figure 5A shows the reflected laser images of experiment 1 in traveling welding process, and Fig. 5B shows the captured laser images of experiment 3 in the stationary welding process. For each case, images 1 and 2 were captured during the pulsed current period, while images 3–36 were captured during the base current period. It was shown that the reflected laser lines have been distorted by the weld metal through observing Fig. 5. Moreover, the variation of the reflected laser lines is regular and periodic contraction or expansion during the base current period.

Because the projected laser lines cover the entire weld pool surface and the captured distorted laser lines are reflected by the weld metal surface, the change of reflected laser pattern can represent the variation of the weld pool surface, and its periodic variation shows the periodic change of weld pool surface. Furthermore, the melt and solidification of a weld pool is a very rapid process. From a mechanical equilibrium point of view, in the weld pool, there exists a balance between the external and internal forces; however, it's a very complicated problem to precisely illustrate the oscillation phenomenon owing to the complex flow pattern of liquid metal in the weld pool. There is an ideal illustration for the restoring force compounded by surface tension and gravity acting on the weld pool during the base current period. With the action of internal forces (such as liquid viscous force, liquid friction force) in the weld pool, the amplitude of weld pool oscillation is changed and decays rapidly (Ref. 35). From an energy equilibrium point of view, this phenomenon is mainly caused by the energy losses of the oscillation: loss of kinetic energy due to solidification of the liquid weld metal at the boundary of the weld pool and dissipation of energy due to the viscosity of liquid metal (Ref. 36).

By analyzing the experimental results, it is found that the clear images can be acquired by the proposed method, and its variation can completely characterize the dynamic process of the weld pool in real-time. The acceptable clearness of the images demonstrated that they can be processed to accurately extract the laser lines shaped by the specular weld pool surface and be used to extract the weld pool oscillation frequency.

Image Processing and Results Analysis

The reflected laser lines are distorted by the irregularities of the weld pool surface. Observation of the reflected images in Fig. 5 shows that the captured images include noise as the laser lines are crossed with each other, gathered in a small area on the imaging plane, or separated from each other. Therefore, to extract the characteristic weld pool oscillation frequency from these images, a new image processing algorithm was developed and the extracted flow chart is shown in Fig. 6, where PSD refers to the power spectral density of signal transferred by the Fast Fourier Transform (FFT) in the frequency domain field.

Image Preprocessing

Being influenced by many factors, such as arc brightness, signal transmission, camera surroundings, and camera scene change, the image is distorted by noise signals. In order to avoid aliasing of the extracted weld pool oscillation frequency and further reducing the influence of noise, the original image is processed by cutting, filtering, and binarizing technology. Since the media filtering can protect the sharp edge information, get rid of the smooth pulse noise in images, and elapse less time, it is adopted in this algorithm. Image 16 in Fig. 5A is selected for illustrating the process. Because the change of gray level between the background and the objective (laser lines) is clear, the threshold segmented method is used to segment the reflected images. The threshold was set at 60. The cut, filtered, and binarized images are shown, respectively, in Fig. 7B–D.

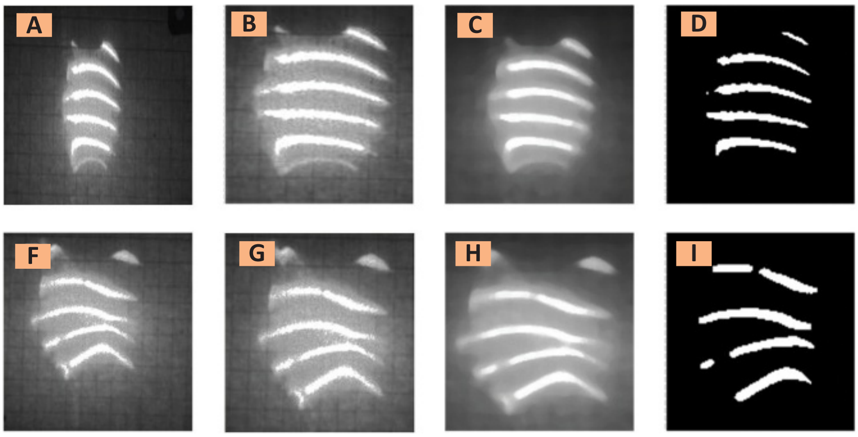


Fig. 12 — A–D — Typical images of experiment 2; F–I — typical images of experiment 5; A, F — original images; B, G — cut images; C, H — filtered images; D, I — binarized images.

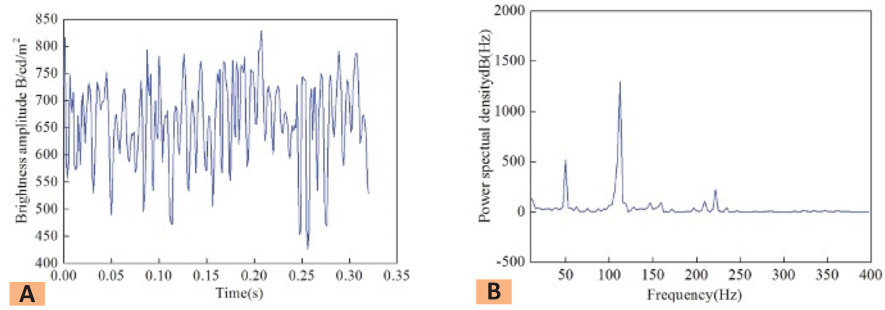


Fig. 13 — Curves of brightness value of experiment 2. A — Time domain waveform; B — oscillation frequency waveform.

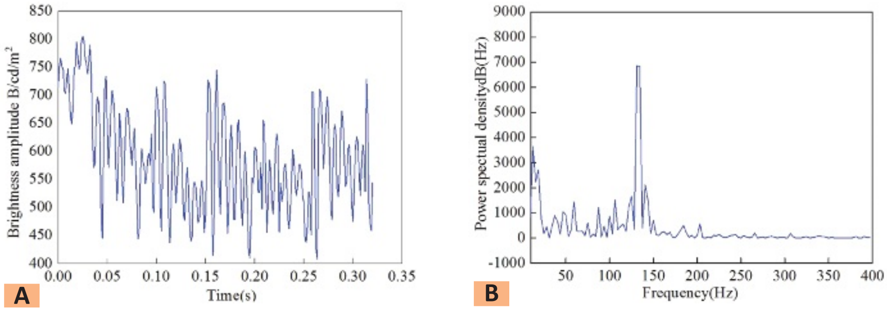


Fig. 14 — Curves of brightness value of experiment 5. A — Time domain waveform; B — oscillation frequency waveform.

Binarized Image Calibration with Rectangular Window

After the completed image binarization process, the periodic contraction or expansion of the laser lines in certain areas become obvious. Within a small rectangular area, its brightness of contraction or expansion differs greatly. In addition, with the corresponding brightness value periodically changing, the reflected laser images periodically change, too. Therefore, using the brightness value of rectangular area can determine the weld pool oscillation frequency. To further extract the oscillation frequency of the weld pool, a fixed area on the image was selected, and the gray level value of the pixels in this area was calculated as well as the sum of them referred to as the value of the weld pool oscillation amplitude.

Different magnitude rectangular windows as shown in Fig. 8 are selected to calculate the gray level value of the pixels in binarized image. With the larger rectangular window, the more elapse time is needed to calculate the sum of gray level of the pixels. If the smaller size window is selected, such as rectangular window 1, useful information about the weld pool oscillation may be lost. Hence, it is very important to select a reasonable size window for processing reflected images in

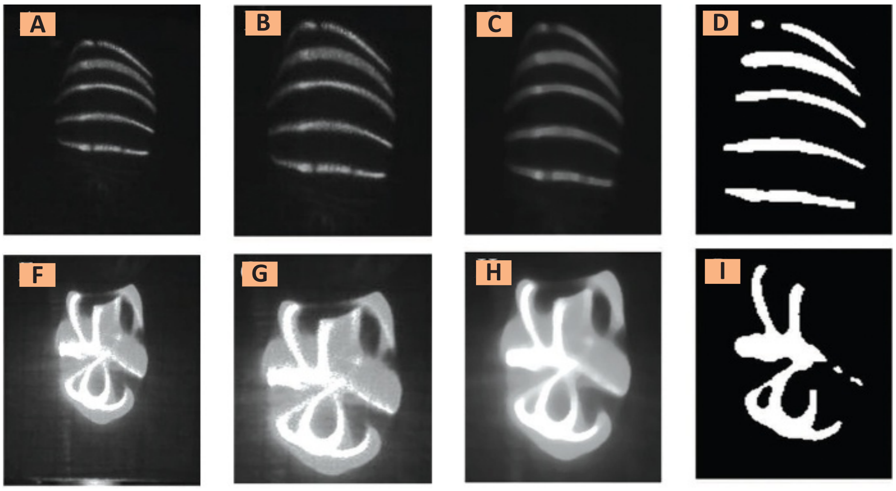


Fig. 15 — A–D — Typical images of experiment 3; F–I — typical images of experiment 4; A, F — original images; B, G — cut images; C, H — filtered images; D, I —binarized images.

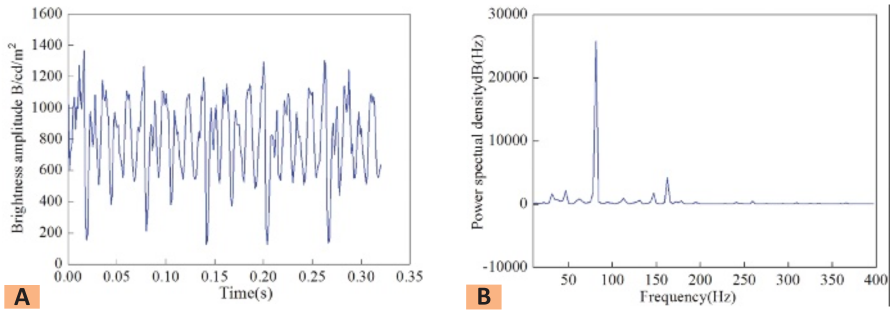


Fig. 16 — Curves of brightness value of experiment 3. A — Time domain waveform; B — oscillation frequency waveform.

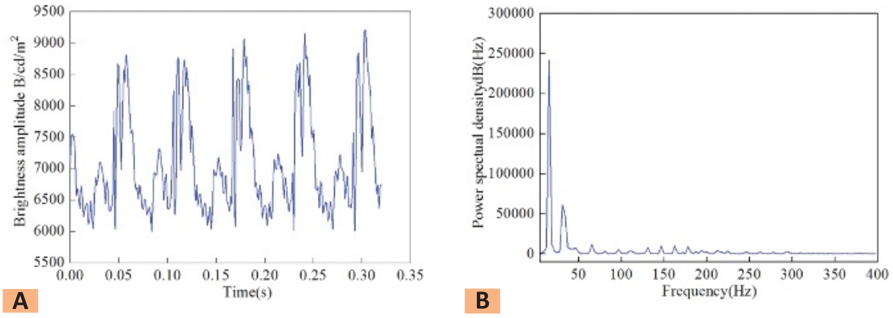


Fig. 17 — Curves of brightness value of experiment 4. A — Time domain waveform; B — oscillation frequency waveform.

real-time. In this paper, an automatic window selection scheme is proposed and shown in Fig. 9, which consisted of the following steps.

Step 1: Input the binarized laser image.

Step 2: Build the image plane coordinate system — Fig. 8.

Step 3: The image is scanned along with the scanning direction, namely the positive x axial.

Step 4: Calculate the sum of gray level value of pixels including the AB line and ensure its center point O'.

Step 5: A rectangular window whose center is point O' is selected, and its brightness value is calculated.

Step 6: Analyze the change of brightness value in time domain field, which is calculated in step 4. If the change is unobvious, the selected window is too small or large. Then, the selected window must be expanded or contracted. Next, repeat step 5 until a suitable window is achieved, where the brightness value of fixed area varies clearly and regularly in the time domain field.

Step 7: In consideration of the requirements for real-time measurement, the selected window in step 6 may need to be further adjusted.

Equation 1 was used to calculate the brightness value of the rectangular window. The image processing algorithm was developed with Matlab2010b software. Taking experiment 1, for example, the continuous 257 images acquired during the base current time were selected from the reflected laser images, and the brightness values of various rectangular window sizes were calculated in the time domain (Fig. 10), respectively.

Figure 10 depicts how the extracted signal changes periodically in the time domain, but this cannot characterize its frequency information. What's more, the curve includes obvious sharpness. By increasing the magnitude of the rectangular window, the variation of the brightness value becomes irregular and the periodicity of the extracted signal becomes less obvious. Therefore, it is important to optimize the size of the rectangular window in order to robustly determine the signal's frequency.

Extraction and Analysis of the Weld Pool Oscillation Frequency

From the transform theory of the signal time-frequency domain, a periodic signal cannot show its frequency in the time domain, but its frequency can be more easily determined in the frequency domain. The relationship between the brightness of reflected laser images and the weld pool oscillation are therefore investigated in the frequency domain. The mapping relationship of the time and frequency domains is set up by the Fast Fourier Transform (FFT) and its inverse transform. A limited long sequence $x(n)$is supposed, and its discrete FFT is shown in Equation 2 (Ref. 37).

Figure 10A shows where the change of periodicity is the most obvious for three rectangular windows. An 81 × 31-pixel rectangular window was selected

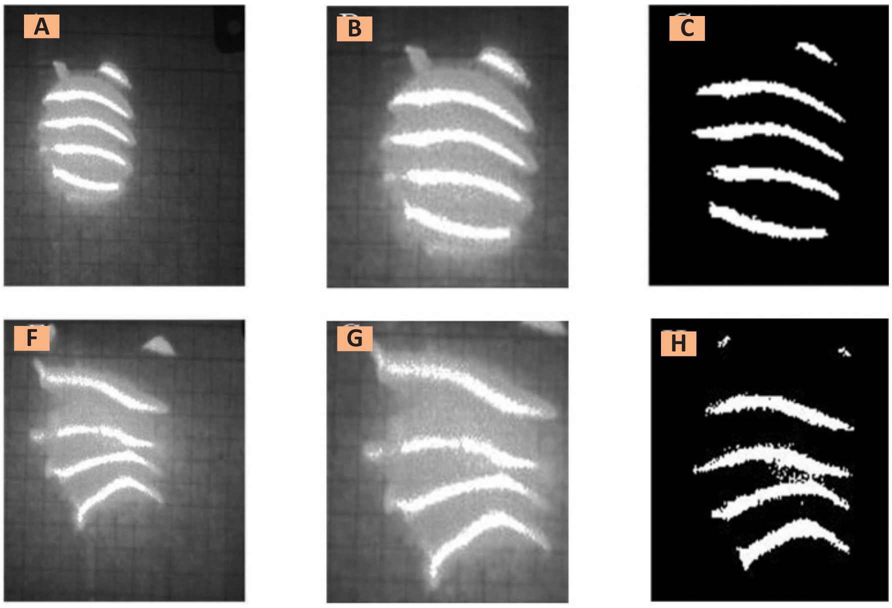


Fig. 18 — A–C — Typical images of experiment 2 without filter processing; F–H — typical images of experiment 5; A, F —original images; B, G — cut images; C, H — binarized images.

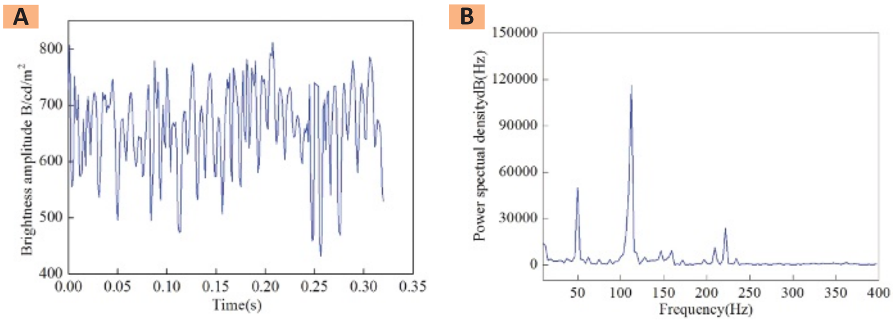


Fig. 19 — Curves of brightness value of experiment 2 without filtering. A — Time domain waveform; B — oscillation frequency waveform.

to explain the extraction process. The gray level value of pixels of continuous 257 images was transformed by the FFT into the frequency domain — Fig. 11. It was found that the extracted frequency from the sequential reflected laser images is approximately 100 Hz. This only, however, represents the change frequency of the 257 images, which needs to be further demonstrated if using the extracted result calculates the practical weld pool oscillation frequency at the same time.

Demonstration of the Image Processing Algorithm's Effectiveness and Robustness

In order to verify the effectiveness and robustness of the image processing algorithm system, two traveling welding experiments, denoted as experiments 2 and 5, and two stationary welding experiments, denoted as experiments 3 and 4, were conducted with the Table 1 parameters, respectively. The reflected laser images of traveling and stationary welding process were captured with the high-speed camera and processed — Fig. 6.

Measurement of Weld Pool Oscillation Frequency in a Traveling Welding Process

According to the flow chart (Fig. 6), the captured images are first preprocessed to minimize the environment influence. The cut, filtered, and binarized images are shown in Fig. 12B and G, C and H, and D and I, respectively.

After preprocessing the image, a 81 × 31-pixel rectangular window was selected and utilized to calibrate the binarized image, and its brightness value was calculated by using the image processing algorithm. Figures 13A and 14A show that the change of brightness is regular and periodic in the time domain field. At the same time, the characteristic frequency of weld pool oscillation, as shown in Figs. 13B and 14B, respectively, was obtained by the FFT.

Figure 13B shows the weld pool oscillation frequency of experiment 2 ranges from 105 to 110 Hz. The frequency of experiment 5 ranges from 110 to 125 Hz. It is obvious that the frequency of experiment 5 is higher than experiment 2. This is due to the difference in average current utilized for each experiment. When the welding speed is the same as welding time, the heat input to the workpiece increases with the average current increasing. To verify the extracted oscillation frequency accuracy of experiments 2 and 5, the practical oscillation frequencies were obtained by a manual count process, which can be operated by the following three steps.

Step 1: Separate the pulsed current time and the base current time images, which have been automatically framed by a high-speed camera, and calculate the frames of base current time images in one pulse period.

Step 2: Calculate the number of oscillations from the reflected images in the base current period.

Step 3: According to the sampling frequency and step 2 results, the oscillation frequency can be obtained.

The practical weld pool oscillation frequency of experiments 2 and 5 is 108 and 120 Hz, respectively, by manual count of the framed laser images. The results show that the extracted oscillation frequency by the proposed image processing algorithm agrees well with the manual count verification.

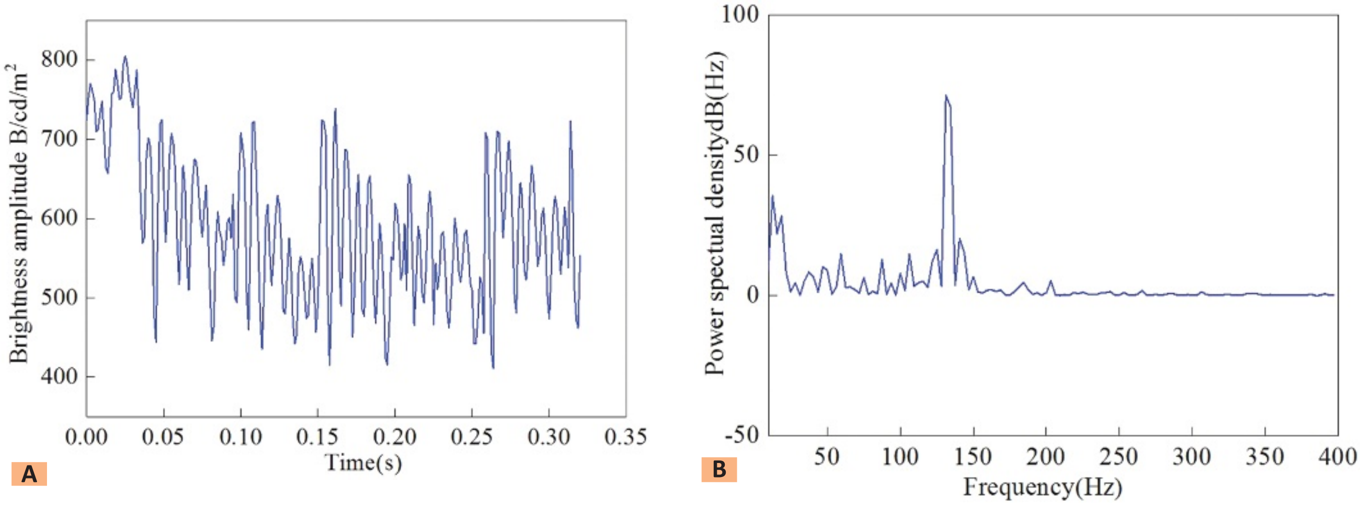


Fig. 20 — Curves of brightness value of experiment 5 without filtering. A — Time domain waveform; B — oscillation frequency waveform.

Measurement of Weld Pool Oscillation Frequency in Stationary Welding Processes

The same strategy of processing reflected laser images is used in traveling welding processes, and the typical reflected laser images are processed — Fig. 15. The 81×31-pixel rectangular window was also selected for calibration of the binarized image. The variable curves of the weld pool oscillation in the time domain field are shown in Figs. 16A and 17A, respectively. The corresponding characteristic frequency of experiments 3 and 4, as shown in Figs. 16B and 17B, respectively, was achieved by the FFT.

When the welding time and the arc length remain a constant in stationary welding processes, the heat input to the workpiece and the volume of melt pool increases with increasing the average welding current. Figures 16 and 17 show that the oscillation frequency of complete joint penetration drops rapidly at the same welding time — 0.32 s. To this end, the correlation of weld pool oscillation frequency and heat input of the workpiece needs to be further investigated based on the achieved characteristic oscillation frequency extracted by the proposed image processing algorithm. If a mathematical model between the welding parameters, i.e., current, welding speed, or arc length, and the weld pool oscillation frequency can be established, the weld joint penetration may be controlled.

A comparison between the extracted frequency and manual count frequency for two cases is conducted and shown in Table 2. From Table 2, it can be seen that both results agree well, and the effectiveness of this proposed image processing algorithm is further demonstrated.

Robustness of the Image Processing Algorithm

The effectiveness of the proposed algorithm has been demonstrated by the four welding experiments described in the previous section. However, the influence of various external or internal factors should be considered when applying the developed image process algorithm to practical applications, thus its robustness needs to be demonstrated. For this purpose, the captured images using the high-speed camera are not preprocessed, such as image filtering and denoising. The information about pool oscillation is directly extracted by the image processing algorithm. In practical applications, traveling welding is used more widely than stationary welding, thus the traveling welding case is only investigated in this section. The original nonpreprocessed reflected laser images for different welding parameters of traveling welding process are shown in Fig. 18. The waveform of experiment 2 in the time domain field and the curve of power spectral density (PSD) are shown, respectively, in Fig. 19A, B. The results of experiment 5 are shown in Fig. 20A, B.

Being compared with Fig. 12, the binarized image of Fig. 18 contains some sharpness. Further analysis of the image processing process determined that the noise produces sharpness, but the characteristic oscillation frequencies are similar to those obtained by the proposed algorithm and verified by the manual count (Figs. 13B and 19B, Figs. 14B and 20B). For example, the characteristic oscillation frequency of Fig. 20B changes from 120 to 130 Hz, which is within the required bounds. Therefore, the influence of noise can be neglected for practical application. This makes it available to use a simpler, real-time image processing algorithm that provides relatively accurate pool oscillation frequency estimates. Therefore, requirements of image processing in real-time are satisfied.

Feasibility Demonstration of Using the Extracted Frequency to Predict the Weld Joint Penetration

Although the proposed laser-vision-based sensing system is able to measure the weld pool oscillation frequency at low pulsed current (the average current is less than 160 A), and the effective-

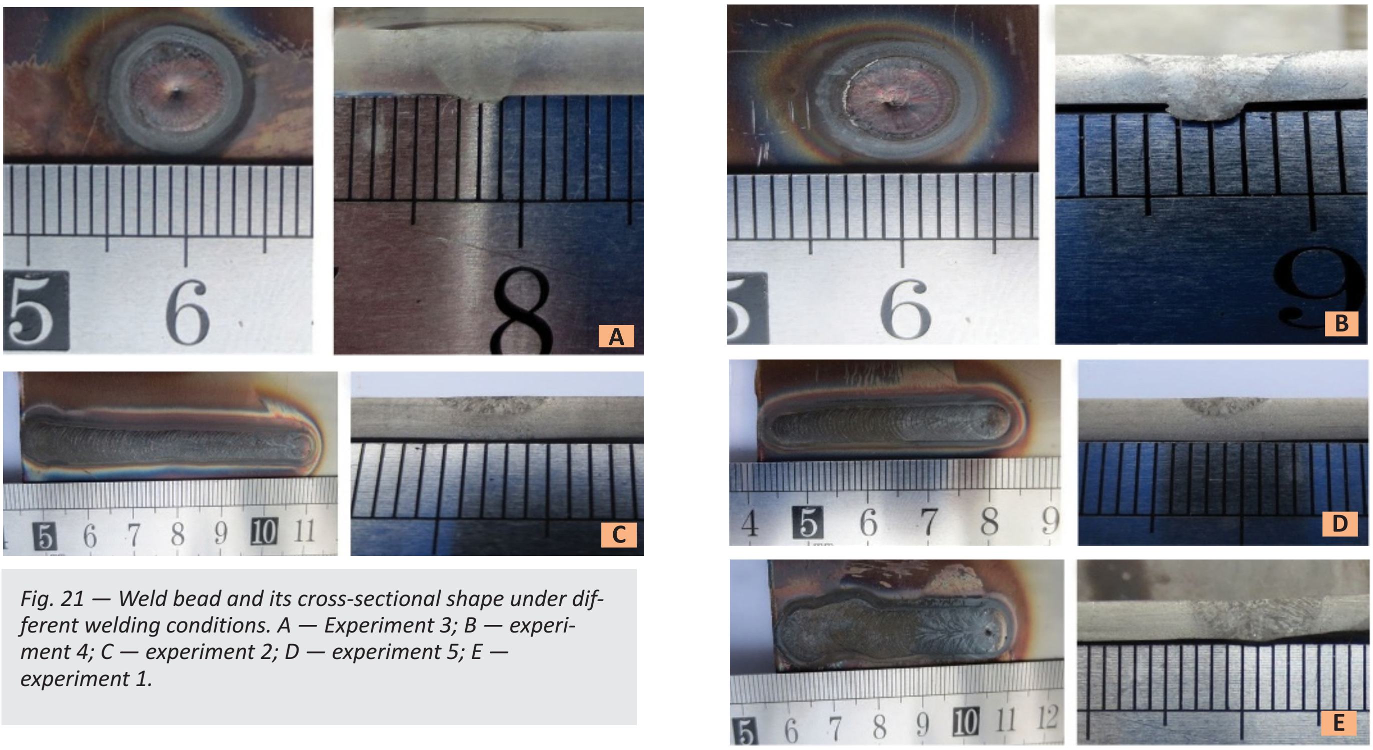


Fig. 21 — Weld bead and its cross-sectional shape under different welding conditions. A — Experiment 3; B — experiment 4; C — experiment 2; D — experiment 5; E — experiment 1.

ness and robustness of the developed image processing algorithm have been demonstrated, its feasibility to monitor and predict the degree of weld joint penetration in a traveling GTA welding process needs to be further investigated. To demonstrate the correlation between the extracted weld pool oscillation frequency and the weld joint penetration, the weld bead and its cross-sectional shape with varying weld joint penetration, respectively, are shown in Fig. 21. The measured top width, backside width, depth, and width/depth ratio are shown in Table 3.

Figure 21A, B shows that the complete joint penetration is achieved. The cross-sectional shapes in Fig. 21A, B show that the backside width of experiment 4 is wider. Figures 16B and 17B show that the oscillation frequency of experiment 4 is lower than experiment 3. They are all less than 100 Hz.

It is known that the weld metal mass or gravity with a given density has a positive relationship with its volume. Hence, the above experimental results further show that the change of pool backside width affects the oscillation frequency, namely as the pool backside width increases, the oscillation frequency decreases for stationary welding process. In traveling welding process, the weld joint penetration increases with increasing the average current for the same welding speed and pulsed current duty-ratio, which can be demonstrated in Fig. 21C–E. Figures 11, 13B, and 14B show that the oscillation frequencies of partial penetration weld pools of experiment 2 and 5 are higher than the frequency for complete joint penetration in experiment 1, and there is an abrupt transition in the frequency from the partial penetration to complete joint penetration. In addition, the smaller weld joint penetration has a higher oscillation frequency of the weld pool.

By analyzing the correlation of weld joint penetration and oscillation frequency for traveling and stationary weld pools, it is demonstrated that the extracted pool oscillation frequency by proposed method is capable of detecting the degree of weld joint penetration.

Discussion

In the past, many researchers have investigated the dynamic behavior of weld pool to monitor and control the weld joint penetration in real-time with many sensing methods as discussed in the introduction. However, each of these methods has its own disadvantages. The machine-vision based method of viewing on the torch side yields only information about the top side shape of the weld pool and no information about weld joint penetration can be obtained. In the case of infrared monitoring the surface temperature distribution, the degree of weld joint penetration can be determined indirectly. However, this technique requires an accurate description of the weld joint and doesn't respond to the changes of material's thickness well. Another way is monitoring the change of arc voltage or arc light emissions that are caused by the weld pool oscillation to measure the degree of weld joint penetration. But, it is very difficult to achieve an accurate signal that reflects the pool oscillation frequency due to the poor signal–to–noise ratio (SNR). To easily and precisely measure the pool oscillation frequency, a new monitoring method was proposed and developed in this paper. Test experiments have been conducted to demonstrate the feasibility of this sensing system. After observing and analyzing the experimental results (Fig. 5), it can be found that the change of reflected images during the base current period is periodic and can represent the variation of weld pool surface through analyzing the fundamental frequency of the measurement. In addition, because the laser light has a higher brightness, good direction, monochromaticity, and coherence, and the strength of arc-plasma radiation rapidly decreases with increased distance from the weld pool, the appropriate position that is placed the imaging plane can be determined and the relative clear reflected laser image can be obtained. Hence, contrasting to the machine-vision method, the arc interference in the images can be effectively avoided.

Since the weld pool oscillation is a damped oscillation during the base current period, further investigation is needed to obtain the characteristic oscillation frequency from the periodic reflected laser images. Thus, a new image processing algorithm was developed and successfully applied. In this algorithm, the brightness value of a rectangular window was selected to characterize the signal of oscillation. There were two advantages for using this signal to calculate the oscillation frequency of weld pool. One is that the change of brightness can directly reflect the contraction and expansion of laser lines, without interference from the bright arc light. The other is that the processing algorithm is simple, requiring minimal processing time and thus can be implemented in real-time. In addition, the selection of rectangular window size plays an important role in achieving a precise oscillation frequency. Three window sizes, 81 × 31 pixels, 12 × 101 pixels, and 181 × 121 pixels were adopted to extract the oscillated signal in the time domain. By comparing and analyzing each curve, as shown in Fig. 10A–C, respectively, it was found that the change of brightness value became more and more irregular by increasing the size of the rectangular window. Next, the signal in the time domain was transferred to the frequency domain by FFT, and the extracted frequency is shown in Fig. 11. The frequency of reflected laser images was verified by manual count of the framed images, and the results agreed very well.

To demonstrate the feasibility of using the oscillation frequency to predict the magnitude of weld joint penetration, several experiments utilizing the Table 1 parameters were conducted, and the corresponding oscillation frequency is measured, as shown in Figs. 13B, 14B, 16B, and 17B, respectively. After analyzing Figs. 13B and 14B, it was found that the oscillation frequency of a larger volume pool is lower than a smaller pool volume. This phenomenon may be explained based on the analysis of causality of the pool oscillations and the influences of various fluid dynamic forces. From the literature (Refs. 38, 39), the reason can be illustrated that the restoring force that acts on the weld pool increases with the volume of weld pool increasing, hence, the weld pool oscillation under higher average current decays more rapidly, and the frequency of experiment 2 is smaller than experiment 5. Furthermore, it has been confirmed that the volume of weld pool has strong relationship with the weld pool oscillation frequency (Ref. 40).

Finally, there can be found a phenomenon that the oscillation frequency of weld pool had an abrupt transition from the partial penetration to complete weld joint penetration. Further, the oscillation frequency of partial penetration is always higher than the complete weld joint penetration in a traveling welding process. The above results provide a new method to monitor the abrupt transition frequency for controlling the complete weld joint penetration.

Although the weld pool oscillation frequency of GTAW-P can be obtained using the developed image processing algorithm offline, its accuracy still needs to be proved by accurate control experiments of weld joint penetration in practical engineering. In addition, the image processing algorithm will be optimized to monitor and control the weld joint penetration in real-time.

Conclusions

A measurement system and an image processing algorithm have been proposed and investigated for monitoring the weld pool oscillation frequency. The following can be concluded from the successful experimental results:

1. The proposed laser vision-based sensing system provides a new way to successfully sense weld pool oscillations.

2. A new image processing algorithm is proposed, which uses the change of gray level of pixels of a binarized laser image to reflect the variation of weld pool oscillation and successfully extract the oscillation frequency. The extracted oscillation frequency from the reflected laser images agrees very well with the manual count results. Moreover, this algorithm quickly and effectively processes the reflected laser images within 20 ms, which may completely satisfy the requirement of measuring the oscillation frequency of weld pool in real-time.

3. The image processing algorithm for extracting the oscillation frequency was accurate and robust, as demonstrated by several offline experiments.

4. The oscillation frequency extracted by this method has a strong relationship with the weld joint penetration in traveling GTA welding process, which is capable of being used to monitor the weld joint penetration. The proposed measurement system provides a good foundation for accurate, real-time control of weld joint penetration.

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Appendix

$$B = \int \left| S(t) \right| d_t = \sum_{k-1}^{n} \left| x(k) \right| \tag{1}$$

where the x (k) is the amplitude of sampled data.

$$X(n) = \sum_{n=0}^{N-1} x(n) e^{-j\frac{2\pi}{N}n} \tag{2}$$

where *X(k)*is the discrete FFT of *x(n)*; *N* is the number of sampling data; *j* represents the plural unit; and *n* is the nth sampling data.

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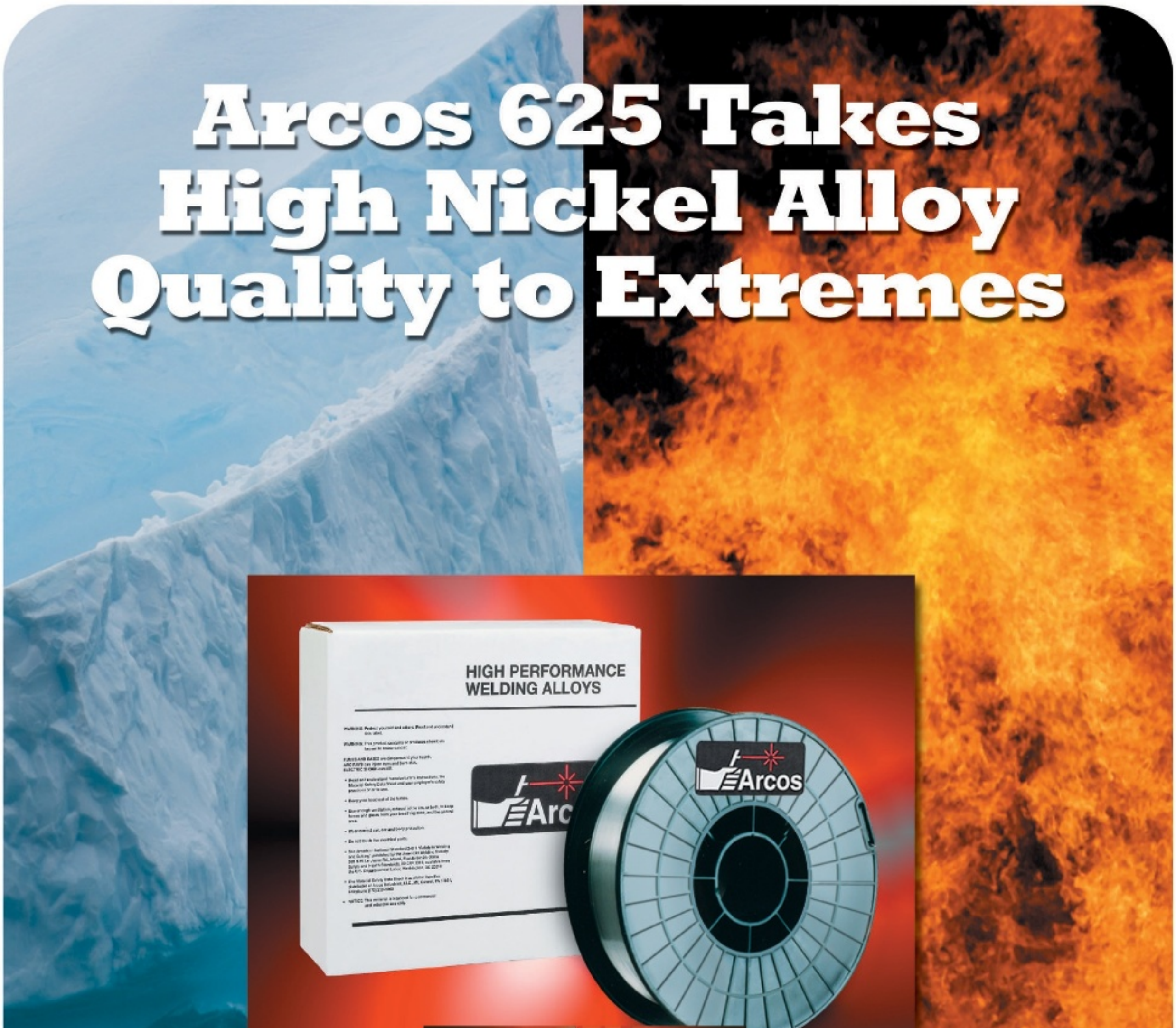

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